

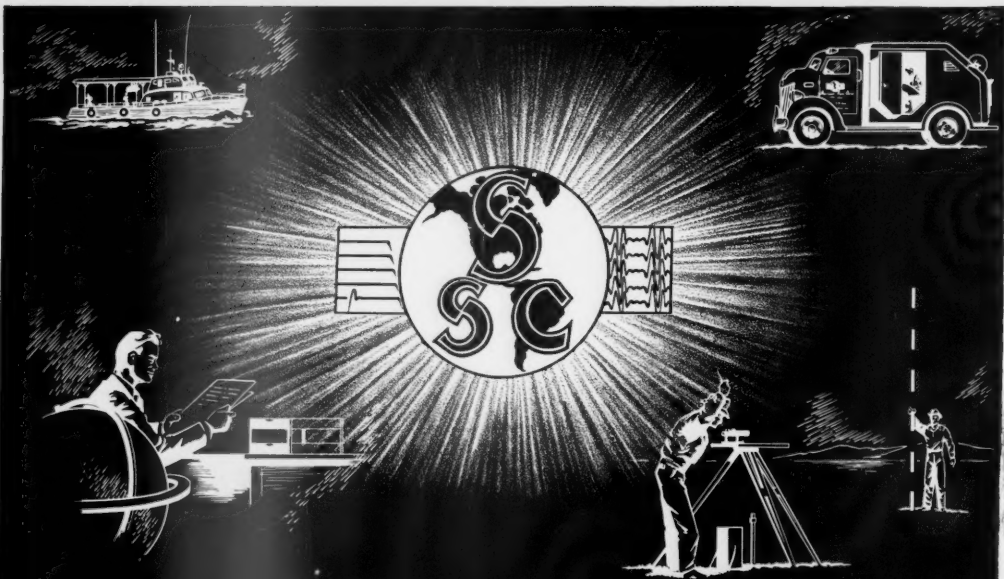
BULLETIN

of the

American Association of Petroleum Geologists

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of the

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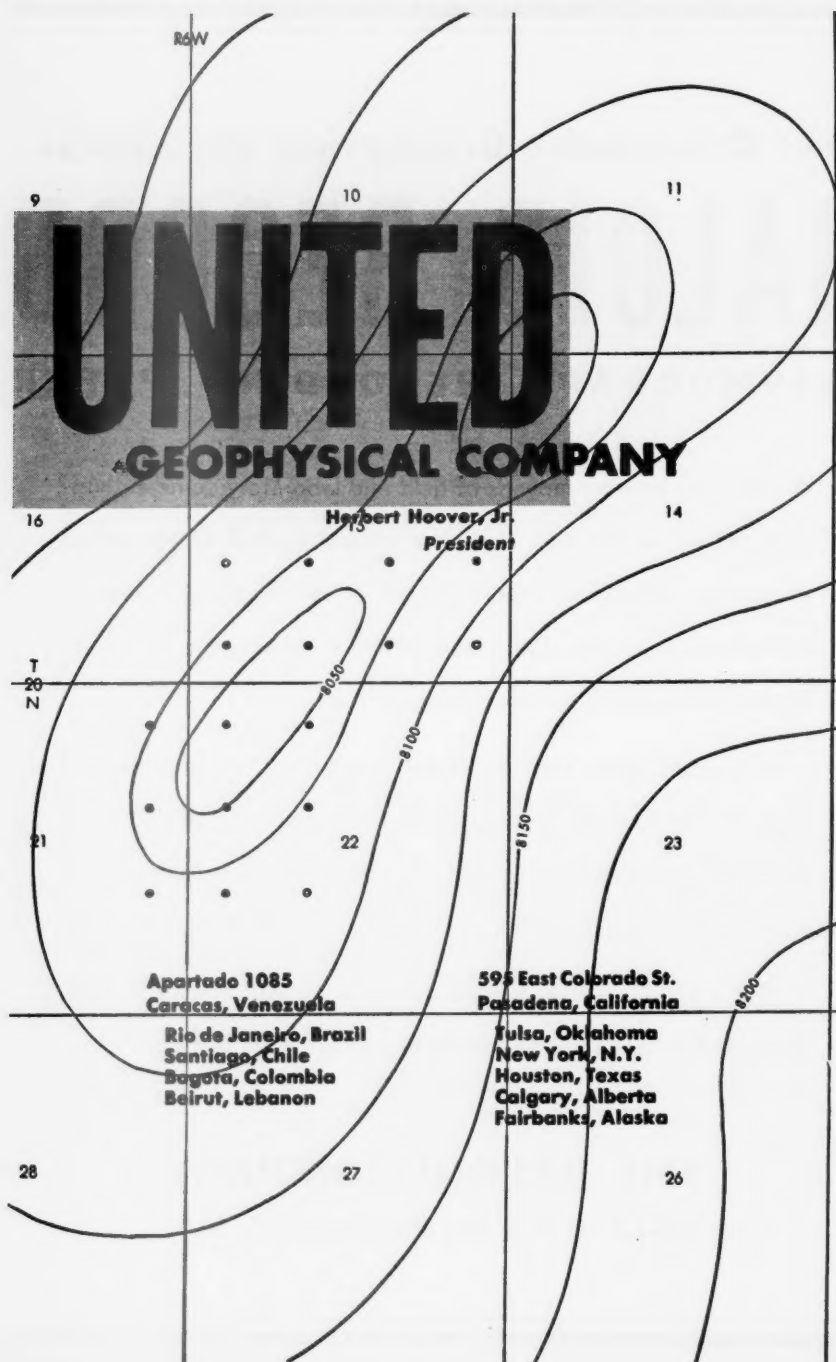
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FRIO SANDS IN LA GLORIA FIELD JIM WELLS COUNTY, TEXAS

Mud (Water & Clay): $R_m = 1.00$ ohm at BHT
 Bit Size: 9 7/8"
 Spacings: AM = 16"
 AM' = 64"
 AO = 18 1/2"

4

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LOG ANALYSIS

1) Water saturation S

R_o for the three sands under study is approximately 2 ohms in neighboring wells.

All three sands have an average true resistivity $R_t = 7.5$ ohms.

$$S = \sqrt{\frac{R_o}{R_t}} = 51.5\%$$

2) Formation water resistivity R_w

With $SP = -50^\circ \log_{10} \frac{R_o}{R_w} = -40$ mv.,

$R_w = 0.16$ approx. at BHT

*(Unclean sands demand lower coefficient)

3) Porosity p

$$F = \frac{R_o}{R_w} = \frac{Q}{0.16} = 12.5 \text{ approx.}$$

$$p = \sqrt{\frac{T}{F}} = 28\% \text{ for } m = 2$$

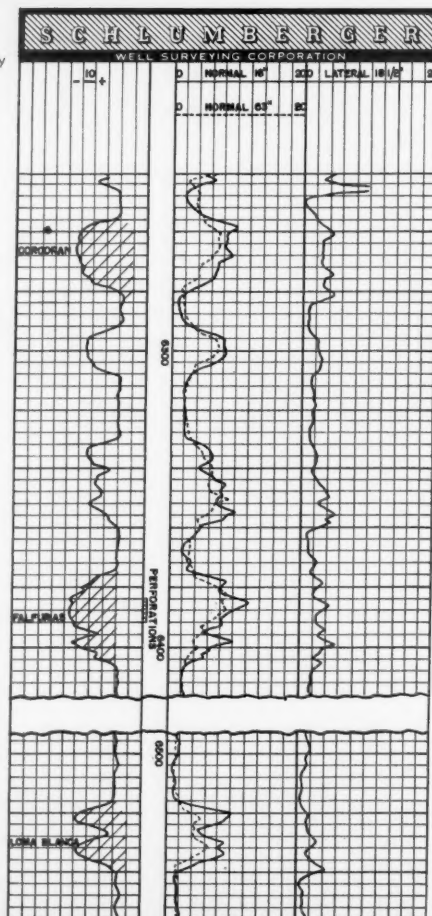
CORE ANALYSIS

	Porosity	29%
Corcoran	Permeability	300 md.
Sand	Residual Water	54%
	Porosity	28.5%
Fallurrias	Permeability	110 md.
Sand	Residual Water	41%
	Porosity	27%
Loma	Permeability	96 md.
Blanca	Residual Water	44%

PRODUCTION RESULTS

Perforated: 6382-90 in Fallurrias

Production Potential: 156 bbl. oil 42° API



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Geology of Atlantic Coastal Plain of New Jersey, Delaware, Maryland, and Virginia

By WALTER B. SPANGLER and JAHN J. PETERSON

Subsurface Geology of Atlantic Coastal Plain of North Carolina

By WALTER B. SPANGLER

Where in the well did the mud go?



DOWELL SPINNER SURVEY located thief formation accurately when lost circulation threatened drilling

When remedial work is necessary to restore lost circulation, a key question is the exact location of the one or more thief zones. An accurate source of this information is a Dowell Spinner Survey, one of the Electric Pilot services.

Spinner Surveys made by Dowell engineers have made it possible to pinpoint the zones where the loss is occurring. With this information the remedial work can be accomplished more quickly and economically, and with the best possible chance of success. For example: After drilling to 8900 feet, loss of returns occurred when the mud weight was increased. No satisfactory material could be found to restore circulation, so a Dowell Spinner Survey was made. This showed the mud

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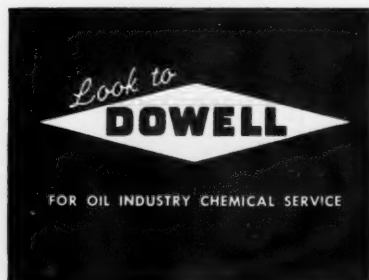
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BULLETIN *of the* AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

DECEMBER, 1949

SEDIMENTARY FACIES IN GULF COAST¹

S. W. LOWMAN²

Houston, Texas

ABSTRACTS

The Gulf Coast of Texas and Louisiana belongs to a world community of Tertiary provinces that have been extensively drilled for oil, and in which the sedimentary characteristics of the producing formations are similar to the characteristics of modern sediments in the same regions to-day. The Gulf Coast is, therefore, one of the geological gateways through which the needs of geology may be expressed in terms of multiple investigations of Recent sediments, and through which, in return, the results of those investigations can be interpreted in terms of the geology of older rocks. The wide spread of sedimentary environments, the slight degree of regional folding, and the extensive development of oil fields from the Rio Grande to the Mississippi River make the Gulf Coast exceptional in its class.

The biological and lithological aspects of sedimentary facies in the Gulf Coast are reviewed. The principal results of investigations of "fossil" foraminifera in the Recent bottom sediments of the Gulf of Mexico are described. The patterns of distribution of foraminifera may be helpful in outlining a frame of reference for further sedimentary investigations in the Recent. General methods of applying the results of investigations to older rocks are described.

INTRODUCTION AND SUMMARY

As the search for oil turns more and more toward a search for new provinces and new trends, we realize the inadequacy of present methods of evaluating the

¹ Read before the Society of Economic Paleontologists and Mineralogists at St. Louis, March 16, 1949.

Manuscript received, April 16, 1949.

Publication No. 7, exploration and production research division, Shell Oil Company, Inc., Houston, Texas.

² Exploration and production research division, Shell Oil Company, Inc., Houston, Texas.

Many of the generalizations discussed in this report are based in part on unpublished results of the work of others. The fact that most of these generalizations are in written and published record, does not detract from the value of having ready-at-hand sources of information which are adequate to check and reformulate them. It is a pleasure to express appreciation for the numerous courtesies extended by members of the staff of the Houston district, exploration department, Shell Oil Company: W. L. Grossman, L. O. Wiringa, E. R. Sauermilch, J. A. Champion, E. A. Vogler, B. J. Stark, and W. G. Baldrige.

All of those members of the paleontological section, Shell Oil Company, who contributed to an unpublished report on "Subsurface Stratigraphy of the Miocene and Plio-Pleistocene of Southern Louisiana," issued in 1940, have thereby contributed to this one, which is the lineal descendant of the Miocene report. These include: W. S. Adkins, R. W. Barker, D. Bell, J. Braunstein, W. M.

significance of sedimentary properties and their patterns of distribution. It is well known that oil occurs almost without exception in porous sedimentary rocks of marine or brackish origin, or in other kinds of rock that are overlain by sediments in such a way that the oil could have migrated from them into its present location. But there are many basins with thick series of sedimentary rocks that have produced little or no oil. Have these been inadequately tested? Are there other sedimentary criteria by which we might diagnose a presently unproductive basin in which a few test wells have been drilled, and thereby select more precisely the area most suitable for further exploration?

The organization of a search for such criteria must take into account the basic dualism of sedimentary rocks (Table I). In the first place they are sediments which are impressed with the characteristics of the environments in which they were deposited, and in the second place they are rocks which contain the record of post-depositional changes that have taken place during the lithification of those sediments. This dichotomy indicates that the place to start an investigation of sedimentary properties is in the modern environments of deposition, and such a plan would find support in the principle of uniformitarianism which states that *the present is the key to the past*. While this principle is philosophically sound, it must be strengthened by its functional corollary, *the past is the key to what needs to be done in the present*. This corollary should be the controlling consideration throughout the entire planning stage of an investigation of Recent sediments, and, of course, the planning stage should continue as long as the investigation was maintained at a research level.

The lower Gulf Coast of Texas and Louisiana belongs to a world community of Tertiary provinces that have been extensively drilled for oil, in which the sedimentary characteristics of the producing series are similar to the characteristics of modern³ sediments in the same regions (Fig. 35). These provinces are the gateways through which the needs of petroleum geology can be expressed in terms of multiple investigations in Recent sediments, and through which in return the results of those investigations can be interpreted in terms of the geology of older rocks.

Cogen, J. B. Dorr, R. Doyle, H. O. Miller, E. H. Rainwater, G. E. Tash, E. A. Vogler, and J. F. West.

The section in this report dealing with time-terminology in stratigraphy is largely the outgrowth of discussions between W. S. Adkins and the writer. The paleontological empiricism described in the section on network-correlation is an interpretation of J. F. West's methods of correlation in the Miocene of Louisiana. The relationships of producing trends and cross trends to sedimentary facies is largely the outgrowth of discussions with O. Wilhelm, D. J. Doeglas, R. H. Nanz, and R. A. Rowland have contributed to ideas on sedimentary petrology and rock chemistry as they apply to investigations of sedimentary facies.

Much of the lore of Gulf Coast stratigraphy was gained through discussions with M. A. Hanna, M. C. Israelsky, and F. W. Rolshausen, chief paleontologists respectively of the Gulf Oil Corporation, the Union Producing Company, and the Humble Oil and Refining Company, Houston, Texas. Israelsky is now with the United States Geological Survey at the Division of Geological Sciences, California Institute of Technology, Pasadena, California.

³ The word "modern" is used to avoid confusion with the geological Recent (Holocene), which is several hundred feet thick in the seaward part of the Mississippi delta. Modern sediment, as used here, refers to the upper few inches.

In the lower Gulf Coast there is very little regional folding, and the distribution of the different kinds of sedimentary rock in the Tertiary is nearly parallel with the pattern of distribution of modern sediments in the Gulf of Mexico and its adjacent coastal plain.

By far the greatest part of the 50,000 feet of presently known Gulf Coast Tertiary is made up of continental beds and sediments deposited in shallow marine (continental shelf) waters. The shallow-water origin of these deposits, coupled with the nature of seaward thickening, demonstrates the occurrence of subsidence during deposition (Fig. 30). The rate of sedimentation was not uniform but was accomplished during a series of transgressions and regressions of the sea which produced pronounced cyclical effects in the sediments (Figs. 3 and 19). All of these cyclical effects are more pronounced in one or two of the broad, transverse synclines than in the balance of the region. The transgressions appear to have been rapid and the regressions slow, with the result that most of the sediments were deposited during the regressive phases of the cycles. These transgressions and regressions produced major changes in the character of the sediments in the vertical direction as well as in a lateral direction extending seaward and landward from the present coast. The net result is a grouping of sediments with similar characteristics in a series of belts generally parallel with the coast (Fig. 3). This parallelism is more pronounced if one compares the sedimentary patterns with the "bay-line" which may be defined as a smoothly curving line connecting the inner margins of the major bays and lakes of the coastal plain (Figs. 1 and 2). These belts of similar sediments correspond so closely with the main producing trends that there can be no reasonable doubt about a causal relationship (Figs. 5 and 6). There are also cross trends in the production which correspond with the broad, transverse synclines of the province and thereby emphasize further the close relationship of sedimentary distribution to the patterns of oil accumulation (Figs. 7-9).

The cause or causes of the relationships between the regional structural pattern, the distribution of sediments, and the distribution of oil fields in the Gulf Coast Tertiary are only partly understood; therefore, we can predict new trends with only partial success. We clearly need to do more work; but, along what lines? A consideration of sedimentary characteristics indicates many potentially fruitful lines by which we might investigate the depositional patterns in the Tertiary rocks and in modern sediments. Since paleontology is further advanced than other branches of sedimentary investigation in the Gulf Coast Tertiary, a logical first step seems to be to map the distributional patterns of Recent "fossils" in various depositional environments. This has been done, and the results are found to be in harmony with stratigraphic interpretation in the Tertiary (Figs. 10-18). Several methods have been devised for coordinating investigations of Recent and Tertiary faunas, and other sedimentary characteristics. All of these methods presuppose valid stratigraphic correlation in the Tertiary.

Empirical methods are available which can produce relatively precise strati-

graphic correlations in a local test area (Figs. 19-20). This leads to a consideration of time-terminology in stratigraphic correlation (Figs. 21-22). Expansion of the problem in an area of very simple structure and stratigraphy requires a consideration of the depositional patterns of the sediments (Figs. 23-24), cyclical sedimentation, and the facies distribution of fossils (Figs. 25-26). Hence, the investigation of the sedimentary patterns, both Recent and Tertiary, and the advanced aspects of Tertiary stratigraphy need to be closely integrated. Taken all in all, the sedimentary conditions in the Gulf of Mexico appear to be exceptionally well developed in the spread of environmental conditions and the slight degree of post-depositional change. Some value might be derived from a comparison of these conditions with other sedimentary provinces. Such a comparison emphasizes the need for additional lines of evidence.

One such line of inquiry is indicated by the close interrelationship between contemporaneous structure and sedimentation as may be shown by comparison of sedimentary and tectonic provinces in the Gulf of Mexico (Fig. 1), by an analysis of the sedimentary characteristics of the Gulf Coast geosyncline (Figs. 30-31), and by a consideration of the hypothesis of subsidence under sedimentary load (Figs. 32-34). The organization of an investigation of sedimentary patterns and stratigraphy without a consideration of the present structural patterns and structural history seems illogical.

The problem of discovering sedimentary criteria for the recognition of petroleum provinces and trends surely involves the study of sedimentation, stratigraphy, and structural history. The diversity of all three of these major fields indicates the need for individualistic methods of approach to the problem, not only within each of these fields but also between any two or all three of them. On the other hand, each of these major fields is made up of many segments, some of which are far enough advanced so that it would be possible to outline planned research at an early stage in the over-all investigation. Therefore, it is thought that a combined attack by individualistic and planned methods of approach within a single program would more probably produce results than either method used alone.

REGIONAL RELATIONSHIPS

Sedimentary provinces and regional structure.—The present Gulf of Mexico with its surrounding coastal plain has the superficial appearance of a single basin of deposition (Fig. 1). However, it possesses at least three major sedimentary provinces. These are: first, the platform-like limestone deposits of the southeast part of the Gulf, principally represented on the wide continental shelves to the west of Florida and Yucatan; second, the continental slopes and the floor of the Sigsbee Deep which are covered with sediment, 20 per cent of which is composed of the shells of free-floating organisms but which also contains characteristic bottom-living faunal assemblages; third, the coastal plain and continental shelf of the northwestern Gulf region where the detritus from more than half the

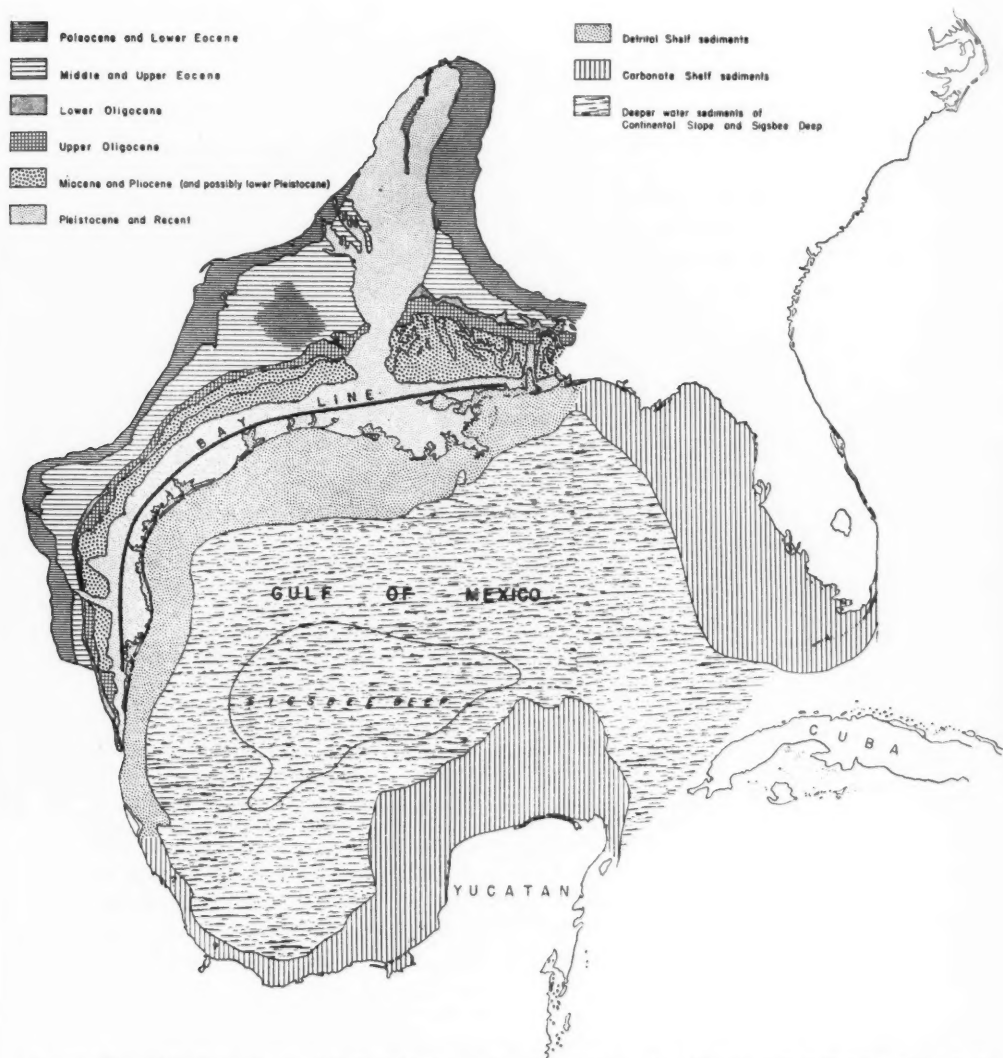


FIG. 1.—Depositional provinces of Gulf of Mexico and surface geology of northwestern Gulf Coastal Plain. Surface geology from Geologic Map of North America (Geological Society of America), compiled by George W. Stose, United States Geological Survey. Scale: 1 inch equals 250 miles.

United States is deposited. The change in strike from north-south at the Rio Grande to east-west at the Mississippi River clearly shows the synclinal character of this northwestern rim of the Gulf. This may be the northwest limb of a geosyncline. By contrast, the geomorphology of the low peninsulas of Florida and Yucatan, projecting far out into the Gulf, indicates their character as platforms. Furthermore, the Upper Tertiary is represented in southern Florida and Yucatan by a few hundred feet of limestone, indicating platform conditions of deposition.

Several thousand feet of Upper Tertiary and Quaternary continental and shallow marine beds are preserved in the northwestern Gulf region in the broad syncline that plunges gently southeast. This northwestern Gulf syncline is di-

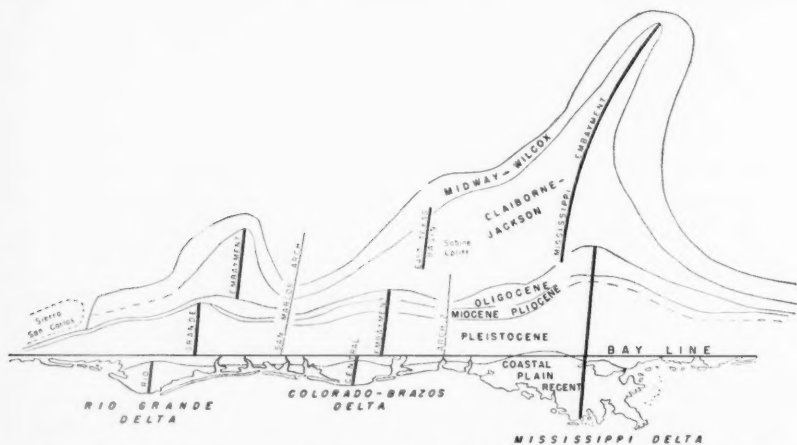


FIG. 2.—Bay-line base map replotted from Figure 1 with bay line straightened and used as reference line. Map shows location of Tertiary and Quaternary outcrops and axes of transverse folds.

vided by five transverse structural features. The arrangement of these features apparently is radial from the central cup of the Gulf, though not from any focal point in that cup. On the south is the Rio Grande syncline. Thence northward and eastward in succession are the San Marcos arch, the central (or Houston) syncline, the Sabine uplift, and the Mississippi River syncline. The persistence of these structural features to the present, and their effect on the sedimentary faces of the region, are indicated by the deltas opposite the embayments and the inter-delta re-entrants in the coast line opposite the arches.

Surface and subsurface distribution of facies.—The surface and subsurface distribution of the various Tertiary units in the Gulf Coastal Plain follow consistent patterns that can be readily summarized in general terms. The first term is a geographic reference line. The various features of the Tertiary are usually described with reference to a generalized coast line. It would be more useful to refer

to the "bay line" which is more nearly parallel with outcrops and subsurface facies patterns than any other geographic features of the coastal area. The "bay line" may be defined as a smoothly curving line that connects the landward edges of the principal coastal lakes and bays (Fig. 1).

This bay line can be represented for convenience as a straight line, and other features of the coast and coastal plain can then be referred to it. For instance, a geological map showing the outcrop of Tertiary strata on a straight bay-line base map would appear as shown in Figure 2. The approximate position of the transverse axes are shown for reference. From left to right, they are Rio Grande syncline, San Marcos arch, central (or Houston) syncline (with the East Texas basin on the north), Sabine uplift, and Mississippi River syncline. The strike of

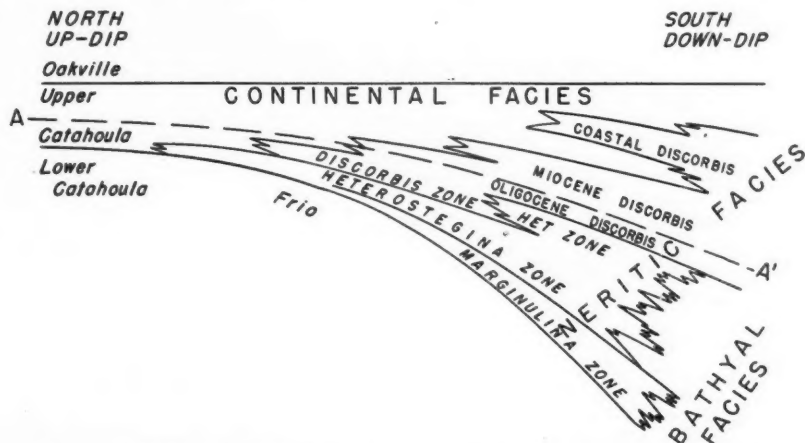


FIG. 3.—Diagrammatic cross section of Anahuac-upper Catahoula (upper Oligocene) cyclical depositional unit, showing "climb" of *Heterostegina* and *Discorbis* zones in down-dip (seaward) direction; generalized central embayment area. AA' is trace of plane parallel with bedding.

the Lower Tertiary is roughly parallel with the bay line except where deflected toward the axes of the embayments. The late Tertiary (Catahoula and Fleming) and the Pleistocene dip at low angles from the outcrop toward the bay line with only slight deflection in the axes of the transverse folds.

All of the major stratigraphic units in the subsurface thicken and become progressively more marine in character from the outcrop toward the bay line, and beyond. Figure 3 is a diagrammatic cross section of the upper Catahoula-Anahuac drawn perpendicular to the bay line in the area of the central embayment. It shows progressive thickening away from the outcrop and both transgressive and regressive facies change. The *Marginulina* zone (lower Anahuac) is transgressive over the Frio. The *Heterostegina* zone (middle Anahuac) is widely transgressive over the *Marginulina* zone, and it passes upward into the regressive deposits of

the several *Discorbis* zones (upper Anahuac) and the upper Catahoula. Similar diagrams of the upper Catahoula-Anahuac could be drawn along any line normal to the bay line from the Rio Grande to the Mississippi River, allowing for minor differences due to changes in the character of the formations along the strike.

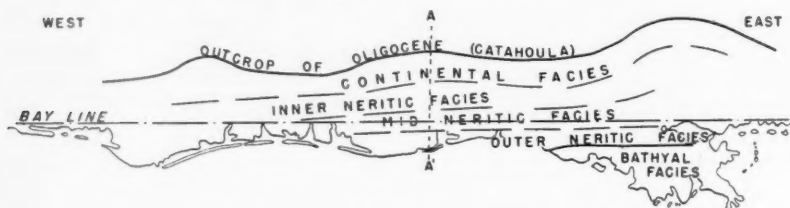


FIG. 4.—Bay-line base map of distribution of facies along plane parallel with bedding and including line AA' in Figure 3.

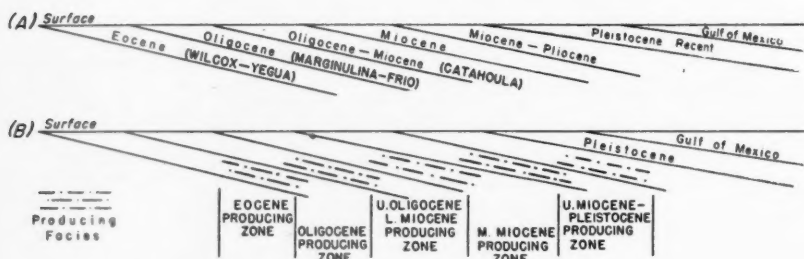


FIG. 5.—Diagrammatic cross section of Texas and Louisiana showing (A) dip toward Gulf, and (B) distribution of producing facies.

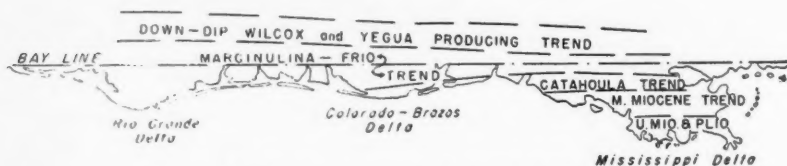


FIG. 6.—Bay-line base map of principal producing trends in Tertiary of Texas and Louisiana Gulf Coast.

Similar diagrams could also be drawn for several other major stratigraphic units in the Tertiary.

Along any plane parallel with the bedding, such as that represented by the line AA' in Figure 3, the facies is progressively deeper-water in character away from the outcrop toward the Gulf. This may be shown diagrammatically on a bay-line base map as in Figure 4. The fresh-water (non-fossiliferous) facies is farthest shoreward. The facies with brackish fauna is next, the shallow marine

facies next, and progressively deeper marine facies follow in successive bands in a seaward direction. This is a general condition in the Gulf Coast Tertiary.

Oil trends and cross trends.—It is notable that the major oil-producing trends (Figs. 5 and 6) follow the same general pattern as shown by the facies distribution in Figure 4. The agreement of oil trend and facies pattern is too consistent to be coincidental. The relationship might be only the distribution of the reser-

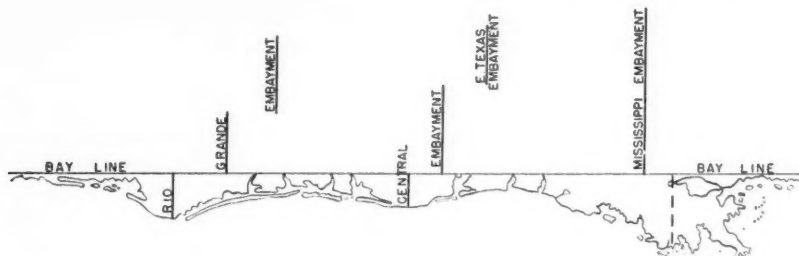


FIG. 7.—Location of transverse embayments.

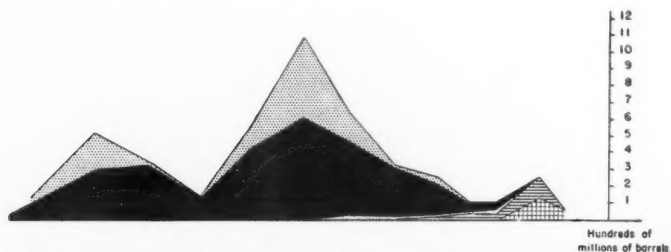


FIG. 8.—Graph of cumulative production by trends and areas transverse to bay line for comparison with location of transverse embayments.

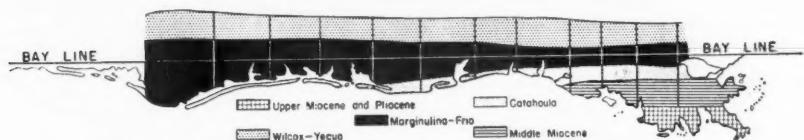


FIG. 9.—Location of principal producing trends and location of transverse areas used in computing graph in Figure 8.

voir sands, but it might also be source beds, or lines of structure, or other, as yet unsuspected, sedimentary characteristics that are essential to accumulation.

In addition to the coastwise trends of oil fields in various formations there are cross trends, in which are concentrated the most productive territory in the embayments. Figure 7 is a bay-line base map showing the location of the axes of

the transverse synclines and arches. Figure 8 is a graph in which cumulative production divided by ages (Eocene, Oligocene, Miocene, and Miocene-Pliocene) is plotted against geographic segments of the Gulf Coast that are bounded by lines perpendicular to the bay line as shown on Figure 9. The richest areas of oil production are concentrated in the synclines, and the lean areas on the arches. The richest of the three synclines occurs in the middle. Here then, there seems to be another relationship between oil accumulation and sedimentary facies. Relationships like these which we can not fully explain, and therefore can not predict, are emphasizing sedimentology in petroleum geology to-day.

SELECTING STARTING POINT FOR INVESTIGATION OF FACIES

Available facts and methods of interpretation in sedimentology.—There is already a great volume of sedimentary facts available in the form of electric logs, micropaleontological data, core analyses, sedimentary logs of rotary cuttings, and various classes of geophysical data. For example, in the Gulf Coast Tertiary there are probably more than 50,000 electric logs which average nearly a mile of hole to a log. Probably more than a million samples have been examined for paleontological markers, resulting in approximately 100,000 identifications. Highly effective techniques have been developed for using these voluminous data. For instance, the continuous detailed lithologic record furnished by the electric log, coupled with the ease of identification provided by the paleontological data, has been a powerful combination for subsurface correlation. Still other techniques and methods of interpreting sedimentary data are being developed in ever widening applications to the problems of oil exploration. Some of the more strongly emphasized branches are sedimentary petrology, rock chemistry, rock physics, micropaleontology, stratigraphy, electric logs and other physical logs, and various other classes of geophysical interpretations. The science of sedimentology already has expanded far beyond the one-man stage, and we are now looking for coordinating principles that will help us see the more significant relationships that exist between the various branches. "Sedimentary facies" appears to be one of these broad concepts.

Definition of facies.—Sedimentary facies are assemblages of commonly related rock properties (Pettijohn, 1949) such as fossil assemblages, lithologic character (composition and texture), and architecture of sedimentary masses (thickness and lenticularity).

"Facies" means aspect, and "sedimentary facies" is the present aspect of a sedimentary rock, whether it be in thin section, hand specimen, or regional occurrence. Facies surely is a rock-descriptive term including both the biological and mineralogical components. It includes their organization in the rock, which, in turn, depends on the sum of the processes of origin and of post-depositional change. The term facies is commonly used in a way that implies horizontal change in the character of the sediments. However, the term surely implies horizontal and vertical continuity as well as change, for without continuity there would be no facies units within the general sedimentary mass. The term facies embraces

both lithologic units (lithofacies) and fossil zones (biofacies), except for those zones which can be shown to be based on lineages.

Environment of deposition.—If we accept the foregoing definition of sedimentary facies, as the product of depositional environment and post-depositional change, then the logical place to begin a fundamental investigation of facies would appear to be in the environments of deposition. This has been the stated choice of petroleum geologists since the survey of research opinion that was conducted by A.I. Levorsen (1939). It was also implicit in the first report of the A.A.P.G. research committee that was presented by W.E. Wrather (1925).

The principle that the present is the key to the past has a corollary which is that the past is the key to what needs to be done in the present. The logic of starting an investigation of sedimentary facies in the Recent is subject to the qualification "if and when we know enough about the geologic past to know where to begin."

TABLE I
SEDIMENTARY VARIABLES

<i>Static Variables</i> (<i>Reflecting Environment</i>)	<i>Dynamic Variables</i> (<i>Reflecting Diagenesis</i>)
Gross lithology, limestone, shale, sandstone	Minor chemical composition, limestone to dolomite
Size, shape, and distribution of detrital grains	Cement
Fossils	Chemistry of rock fluids
Sedimentary textures and structures	Density and porosity
Radioactivity and magnetism	

Fortunately there are certain major categories of facts which are so consistently arranged in sedimentary rocks that some interpretation of depositional environment can be made in rocks as old as the Archean (Pettijohn, 1943). Increasingly detailed interpretations of depositional environment can be made in successively younger rocks where the effects of post-depositional processes are less pronounced and where there are faunas with increasingly modern characteristics.

In a search for sedimentary criteria by which we may identify the environment of deposition in sedimentary rocks, it may be useful to classify the sedimentary variables as static and dynamic (Table I). Among the static variables may be listed those properties which retain their original depositional characteristics (although they may be somewhat modified by post-depositional processes) as follows: (1) gross mineral composition of the solid rock, for example, limestone, shale, or sandstone; (2) size, shape, and distribution of detrital grains; (3) fossils; (4) sedimentary structures; (5) possibly some mass effects related to chemical composition, such as radioactivity and magnetic properties. Among the dynamic variables might be included: (1) minor changes in gross composition, for example, limestone to dolomite; (2) cement; (3) chemical composition of rock fluid; (4) character of those parts of the mineral assemblage which are susceptible to post-depositional change through differential loss of some minerals and authigenic gain of others; (5) some physical mass properties such as density and porosity. Stated in another way, the static variables are those which should be useful in

making interpretations of depositional environments. The dynamic class, on the other hand, should serve in making interpretations of post-depositional change.

Fossils as criteria of depositional environment.—At present the fossils appear to be the most useful criteria for making environmental interpretation in young sedimentary masses like the late Tertiary of the northern Gulf of Mexico region. This value is produced by several factors: (1) the great abundance and fine state of preservation of fossils in marine and brackish facies; (2) the striking gross similarity between the biofacies of the late Tertiary and the Recent; (3) the delicate adjustment of organisms to preferred environments as judged by their abundance-distribution in the Recent; (4) the great number of species in the average sample; (5) the ease and security of identifying the species; (6) the hundreds of thousands of samples of the Tertiary that have already been prepared for paleontological examination, and are available for further study; (7) the fact that the paleontological branch of sedimentology is more advanced in the Gulf Coast Tertiary than other branches, such as sedimentary petrography and rock chemistry.

For several years there has seemed to be no reasonable doubt that enough is known of the biofacies in the late Tertiary of the Louisiana and Texas Gulf Coast to serve as a guide for one of the more promising lines of investigation in Recent sediments. This is particularly true of the foraminifera which are delicately adjusted to Recent environments and also to sedimentary facies in the Tertiary as judged by their patterns of distribution. They are also by far the most abundant fossils in the Tertiary and the most abundant fossil-producing organisms in the Recent. The facies distribution of the Anahuac-upper Catahoula shown in Figure 3 is based largely on an interpretation of assemblages of the foraminifera. It is representative also of the biofacies interpretations that have been made in other parts of the Tertiary.

DISTRIBUTION OF FORAMINIFERA IN RECENT SEDIMENTS OF GULF OF MEXICO

Methods of collecting samples and evaluating data.—Fortunate circumstance provided an opportunity to undertake the study of Recent foraminifera of the region 9 years ago when the S.S. *Hydrographer* of the United States Coast and Geodetic Survey commenced a survey in the northern Gulf of Mexico. This survey continued during three summer field seasons and included parts of the continental shelf and slope from the Mexican boundary to the area off continental Florida. Several hundred samples of bottom mud were collected and were made available to a study group of the Houston Geological Society. These samples were supplemented by private collection from fresh, brackish, and shallow marine environments. Samples of bottom water were collected from representative brackish-water localities, and the chlorinity was evaluated by titration with silver nitrate. Figure 10 shows the location of the three main profiles along which samples were taken.

The samples that were collected by the *Hydrographer* were, for the most part,

taken from the anchors of buoys used for surveying purposes. There were, in addition, several grab samples and a few cores. The samples collected in brackish water were mostly grab samples. Such samples come from below the environment of deposition and may be thought of as incipient rocks. The faunal assemblages are not living but are fossil. The gross character of the sampling techniques approximates usual geological sampling. Changes due to seasons, or short-swing climatic cycles, are averaged in treating the top foot or so of sediment as a unit. Finer sampling will be needed in the future to work out the details, but gross sampling appears to have been well adapted to the needs of the preliminary investigation.

A rough check was made on rate of vertical change in faunal distribution in

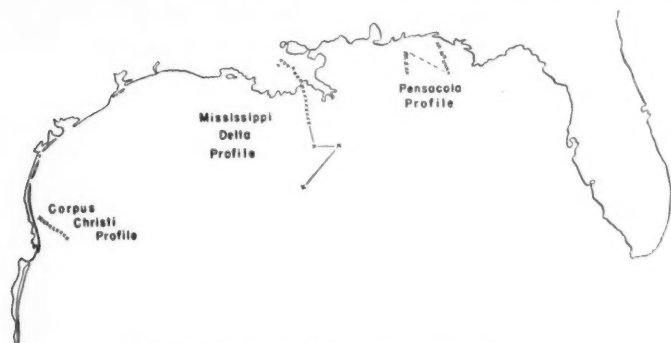


FIG. 10.—Location of profiles of Recent samples.

one of the bays on the Mississippi delta. The top, middle, and bottom foot of 3-foot cores were found to contain the same general fauna in a profile of twenty-two cores across the bay (Fig. 18).

The foraminiferal assemblages have been evaluated by counting the individuals of each genus in a representative fraction of each sample. Bar graphs have been prepared showing the generic percentages for each sample, and these have been compiled on maps and profiles showing the distribution of genera relative to certain gross features of the environment.

Objectives.—The immediate objective of this work, of course, was to improve our knowledge of the significance of foraminiferal faunas in terms of environment. There were two ultimate objectives. These were, first, to improve our ability to use assemblages of fossil foraminifera as criteria of depositional environments, and, second, to help disentangle environmental and evolutionary factors in the three-dimensional distribution of fossil faunas; in other words, to help test the nature and the validity of so-called guide fossils and fossil assemblages.

A third objective has developed during the course of the work, namely to use the distribution of faunal assemblages as part of a preliminary framework within

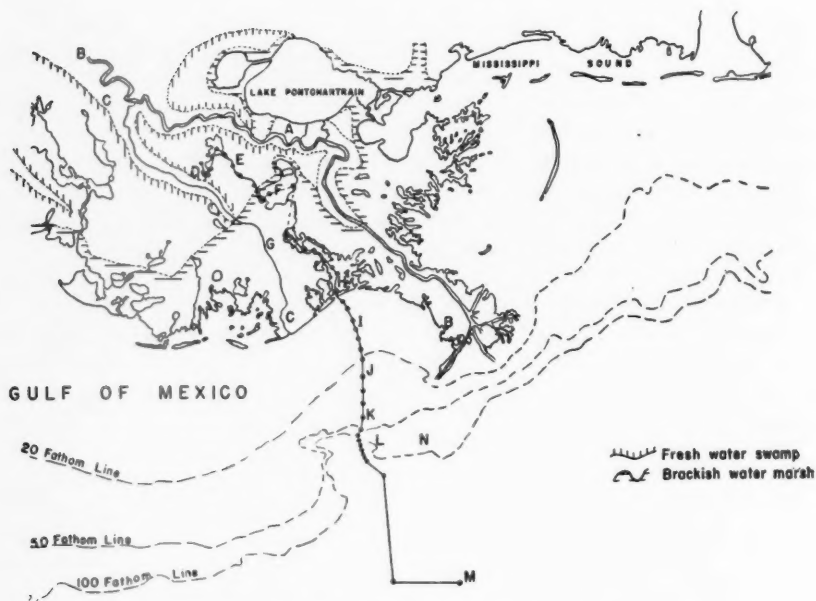


FIG. 11.—Map of location of samples on profile shown in Figure 12.

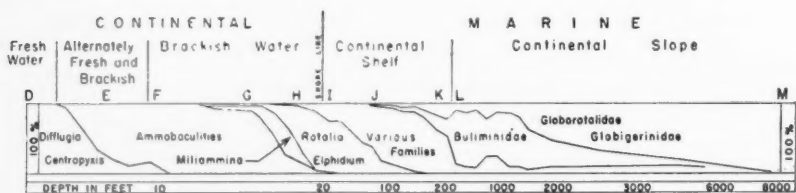


FIG. 12.—Distribution of foraminifera in Mississippi delta region and Gulf of Mexico. Graph composed of connected bar graphs; at any station in horizontal scale, graph gives percentage abundance distribution of foraminifera. For detail, see Figure 13.

which to outline an investigation of other properties of sediments and the processes that are operative in the environments of deposition.

Results of preliminary investigation of Recent foraminifera.—The close relationships between the distribution of faunal assemblages and of other sedimentary characteristics is well shown in the area of the Mississippi delta, particularly across an elongate drainage area south of the city of New Orleans (A, Fig. 11) and outward from the shore to the continental slope. The continental part of this area is contained by the natural levees of the Mississippi River (B, Fig. 11)

on the north and east, the natural levees of Bayou Lafourche (C, Fig. 11) on the west, and the Gulf of Mexico on the south (Fig. 11).

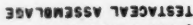
The northwest end of this segment is covered by fresh-water cypress swamps and grassy marsh, dotted with lakes and cut by sluggish bayous (D, Fig. 11). Foraminifera are absent but are represented by their close relatives *Diffugia* and *Centropyxis* (D, Figs. 11 and 12). Gulfward, there is apparent grading of the fresh-water assemblage into brackish faunas (E, Figs. 11 and 12). This may be due to gross sampling techniques used on thinly interbedded brackish and fresh-water deposits that are produced by alternations of flood- and low-water. The fresh-water element of the fauna is not present in Lake Salvador, which, at the time of sampling, contained 100 parts per million of chloride (F, Figs. 11 and 12). That small amount of chloride was apparently enough to kill the fresh-water *Centropyxis* and *Diffugia*. The foraminiferal genus *Ammobaculites* is the dominant genus in what may be classed as weakly brackish environments in the range from 100 to 5,000 parts per million chloride. *Ammobaculites* and *Miliammina* characterize the strong side of that chlorinity range (G, Figs. 11 and 12). The bottom deposits are dark to light, bluish gray, sandy muds with extensive banks of clam shells (*Rangia*) particularly in Lake Salvador. From 5,000 to 15,000 parts per million, *Rotalia* and *Elphidium* take on the dominant role, the bottom sediments being blue, variably sandy mud with scattered oyster banks (H, Figs. 11 and 12).

There is no sharp distinction "at the shoreline" between brackish and marine assemblages, because the shoreline is breached by a tidal pass through which the tides race at a sufficient rate to scour a hole 160 feet deep. This is 150 feet below the level of the surrounding bottom. There are minor differences between the marine and brackish assemblages, such as a great amount of variation in *Elphidium gunteri* var. *galvestonensis* and *Rotalia beccarii* var. *tepida* in the changing environments of the bay as compared with little variation of the same forms in the relatively stable waters of the Gulf. However, the generic assemblages grade from the brackish bay to the somewhat less brackish shallow waters of the Gulf.

Seaward, it is possible to discern three, rather vague divisions of the faunas on the continental shelf (I, J, K, Figs. 11 and 12. Some details of Fig. 12 shown in Fig. 13). These characterize the inner shelf, the middle shelf, and the outer shelf. Additional work in the Tertiary indicates that this tripartite division of the continental shelf fauna is usable.

A striking faunal change takes place within a narrow depth range at about 300 feet (L, Figs. 11 and 12). This faunal change marks the boundary between the neritic (continental shelf) and bathyal (continental slope) realms (Haug, 1907, pp. 88-89; Tercier, 1939) and is far more conspicuous than any changes on the continental shelf. Outward toward the abyss, the sample control is too scattered to recognize faunal provinces or subprovinces, but recent work at Woods Hole on an abundance of samples from the deeper parts of the Gulf has demon-

PERCENTAGES SHOWN FOR MOST INLAND STATIONS ARE BASED ON SEVERAL SAMPLES



GION AND THE GULF OF MEXICO

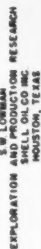


FIG. 13.—Distribution of foraminifera in Mississippi delta area and Gulf of Mexico.

strated the presence of belts of distinctive faunal assemblages that apparently can be correlated with depth.⁴

The foraminiferal associations discussed to this point are bottom-living types (at least during adult stages of their life history), and they inhabit open-water environments which are assumably well oxygenated. There are two other groups of foraminifera which inhabit two other classes of environment: (1) the free-floating (pelagic) genera which live near the surface of the water; and (2) the bottom-living (benthonic) inhabitants in foul, brackish, marsh pools.

The shells of the dead pelagic animals (Globorotalidae and Globigerinidae) rain down on the bottom, and form the principal component of the death assem-

TABLE II
ENVIRONMENTS CONTROLLING DISTRIBUTION OF FORAMINIFERA

1. Free-floating
Orbulina, *Globigerina*, *Globorotalia*
2. Bottom-living; stagnant (?)
 - A. Brackish
Haplophragmoides, *Trochammina*, *Ammonastuta*
 - B. Marine
Haplophragmoides, *Trochammina*, *Cyclammina*, *Bathysiphon*
3. Bottom-living; open-water
 - A. Fresh-water
Centropyxis, *Diffugia* (not foraminifera, but closely related)
 - B. Weakly brackish
Ammonaculites
 - C. Moderately brackish
Ammonaculites, *Rotalia*, *Elphidium*
 - D. Strongly brackish and nearshore marine (inner neritic)
Rotalia, *Elphidium*, *Miliolidae*
 - E. Mid-continental shelf (mid-neritic)
Great abundance of genera and species; dominance of *Rotaliidae*, especially *Cibicides*
 - F. Outer continental shelf (outer neritic)
Great abundance of genera and species; conspicuous number and variety of *Lagenidae*
 - G. Upper part of continental slope (inner bathyal)
Dominance of *Buliminidae*, especially *Uvigerina*, and *Bolivina*
 - H. Other depth-zone faunas said to be present in deeper parts of Gulf according to current results of Fred B. Phleger, in process of preparation for publication.

blages in the deeper parts of the Gulf (M, Figs. 11 and 12). They tell little about bottom conditions except the ratio of production of pelagic shells to the rate of bottom deposits from other sources.

In the foul brackish-water marshes the bottom deposits are black muck with very abundant carbonized plant remains, and assumably reducing conditions of deposition. The predominant genera are *Haplophragmoides*, *Trochammina*, and *Ammonastuta*. The first two are found also in association with *Cyclammina* and *Bathysiphon* in marine deposits in which mineral and plant components suggest low oxygen content. Similar faunas, dominated by *Haplophragmoides* and *Trochammina* are present in the salt marshes from San Diego to San Francisco on the Pacific Coast. They are present, for instance, in marshes at the south end (Dumbarton Bridge area) of San Francisco Bay where the salinity is high enough for commercial salt production by the evaporation process. On the other hand,

⁴ Oral communication from Fred B. Phleger.

the brackish marshes of Louisiana that harbor this fauna occur from the most dilute to the most saline parts of the brackish-water lake and bay area in the Mississippi delta. *Haplophragmoides* and *Trochammina* are found also in association with *Cyclammina* and *Bathysiphon* in some marine deposits in which the mineral and plant components suggest low oxygen content. Therefore it is clear that this group of bottom-living foraminifera does not characterize any part of the normal profile that extends across open water environments and well oxygenated conditions, from fresh-water to marine conditions. *Haplophragmoides*, *Trochammina*, and their associates tolerate bottom conditions that the normal assemblages do not tolerate.

There appear, therefore, to be at least three major environments and several minor ones which control the distribution of foraminifera in the continental and

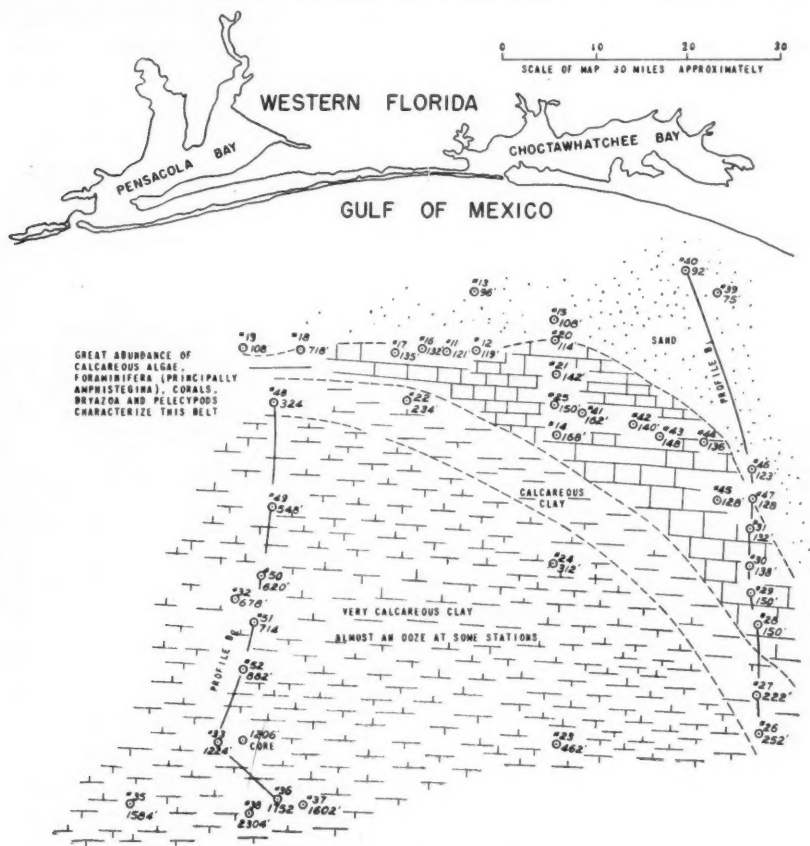
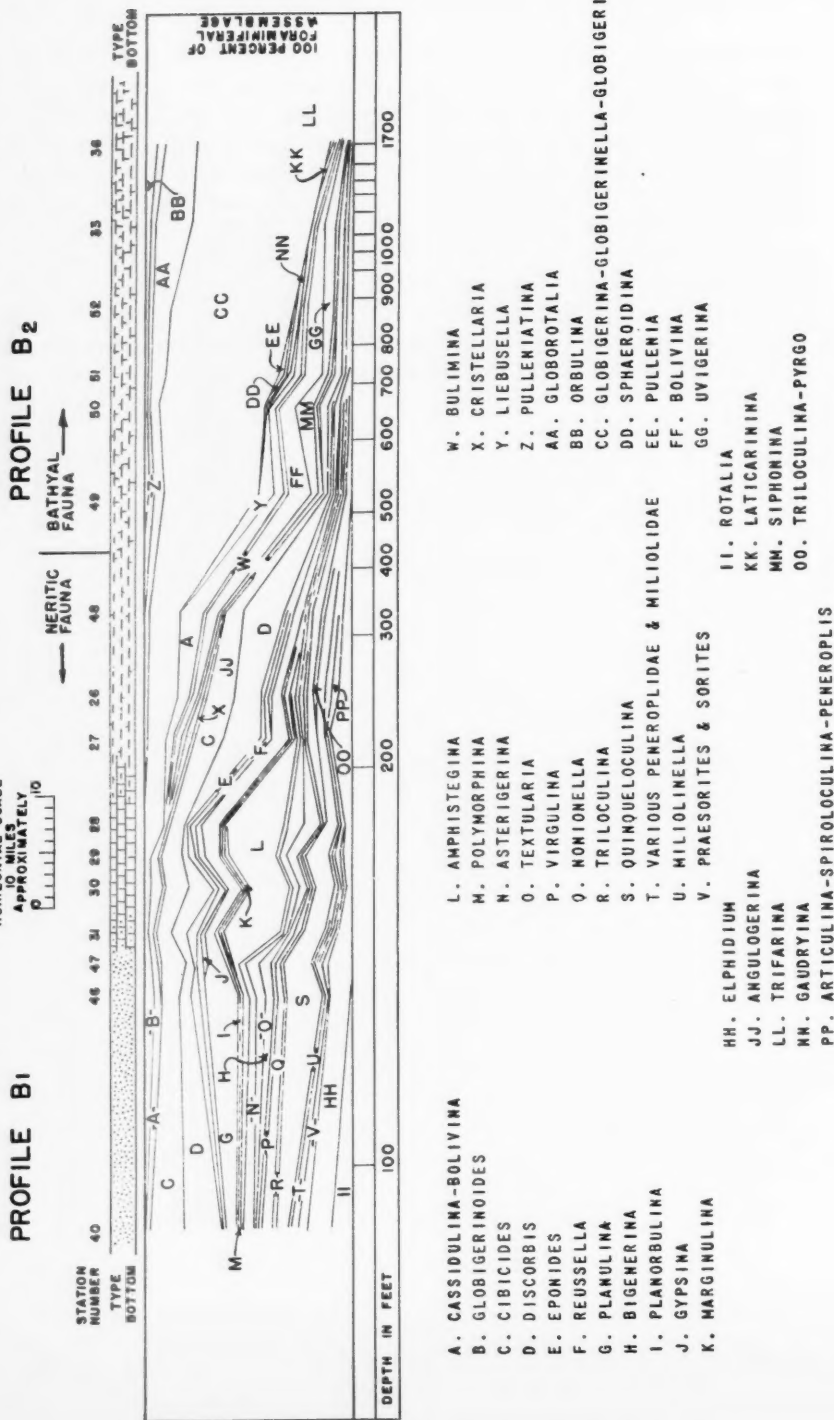


FIG. 14.—Map of location of samples on profiles shown on Figure 15.

DISTRIBUTION OF SOME RECENT FORAMINIFERA
FROM THE GULF OF MEXICO SOUTH OF PENSACOLA AND CHOCTAWHATCHEE BAYS, W. FLORIDA



marine areas of the Mississippi delta region. These are shown in Table II. Table II is not intended as a complete list of even the major faunal facies for any area other than the turbid bottom deposits of the northwestern Gulf of Mexico, or for any age other than the Recent. Within the Tertiary of the Gulf Coast, there are several distinctive faunal facies that are not represented in the Recent of the region. Within the Recent itself in the northwestern Gulf region, there are isolated patches of fauna that appear to represent clear-water environments. They are located on the tops and upper flanks of submerged banks where there are local environments assumably raised above the level of turbid bottom conditions. One of the banks, from which bottom samples are available, occurs off the southwest pass of the Mississippi River (N, Fig. 11). Its top is about 200 feet below the surface and 100 feet above the surrounding bottoms. The local fauna is dominated by the genus *Amphistegina*. This genus is present in abundance in the clear water off the coast of western Florida (Fig. 14-15) but is absent from the turbid continental shelf in the Mississippi delta region.

A comparison of the faunal assemblages in the clear-water environment off western Florida (Figs. 14-15) and the turbid area off the Mississippi (Figs. 11-13) gives some idea of the differences which may be produced in the faunal facies even within equivalent depth bands in the neritic and bathyal realms. The assemblages on the continental shelf off the coast of South Texas (Figs. 16-17), on the other hand, are similar to those in the Mississippi delta region. Scattered samples between the Rio Grande and the Mississippi profiles indicate that the turbid fauna is typical of that area.

Temperature versus over-all physics and chemistry as controlling factor in faunal distribution.—The continental area of the Mississippi delta presents a striking correlation between the distribution of foraminiferal assemblages and the distribution of the gross chemical and physical characteristics of the environment. Temperature alone appears to play little direct part in these differentiations, because all the environments are so shallow as to be affected by the diurnal temperature range.

In contrast to the abundant evidence of chemical controls in the distribution of continental faunal assemblages, there are few data available that bear on deeper marine benthonic environments except depth and temperature. Such data in other regions have been interpreted by Natland (1933), Parker (1948), and Phleger (1942) as suggesting direct or indirect temperature control of the distribution of marine faunal assemblages. The effect of temperature on the distribution of plants and animals is well known both on land and in the sea (Hess, Allee, and Schmidt, 1937; Hutchins, 1947). However, it is only one of many factors that make up the total environment. For example, the very striking change in the faunal assemblage that takes place at a depth of about 300 feet may be related to the photic and diphotic zones. Weeds grow in the photic zone which extends to a depth of about 300 feet, and Earl H. Meyers has shown that many species of foraminifera live on the weeds.

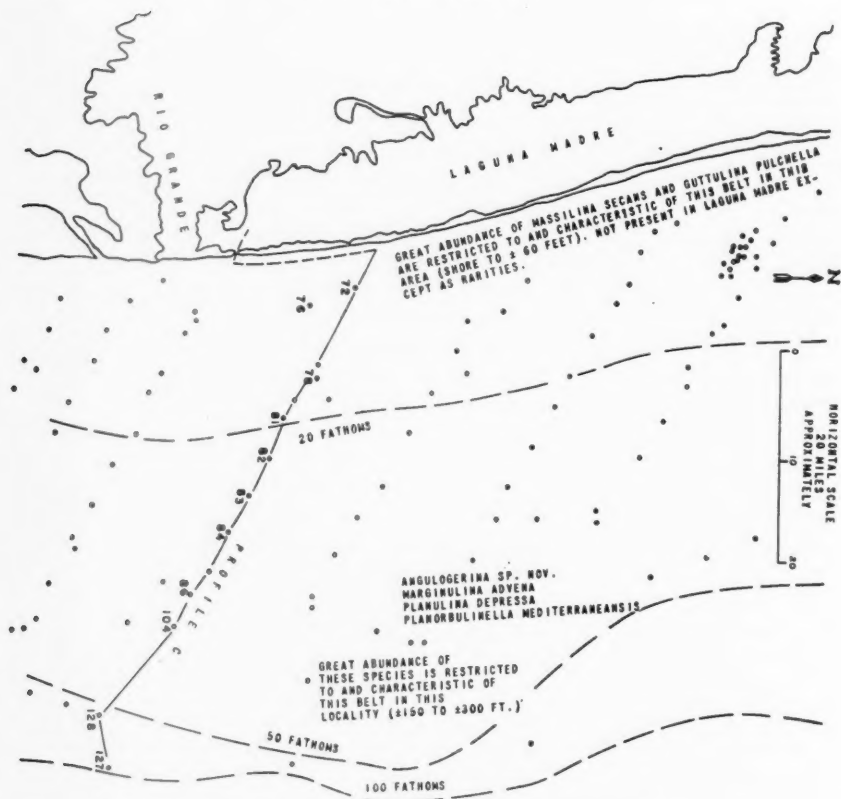


FIG. 16.—Map of location of samples on profile shown on Figure 17.

This point is highly important to the correlation of bio- and lithofacies. If marine faunal assemblages are controlled primarily by temperature, then there may be little correlation between the faunal and mineral assemblages. But if, on the other hand, the primary control is the over-all physics and chemistry of the bottom environment, then there may be close correlation between the assemblages of shells and other sedimentary particles, particularly those substances which are formed in place, possibly including mother substances of oil.

Possible mechanical transportation of foraminifera.—The value of foraminifera in making interpretations of depositional environments has been questioned on the assumption that shells of recently dead animals might contain pockets of gas that were caused by putrefaction of dead protoplasm. It has been suggested that these gas pockets might act as float chambers, causing widespread mechanical dispersal.

DISTRIBUTION OF SOME RECENT FORAMINIFERA FROM THE GULF OF MEXICO EAST OF THE RIO GRANDE RIVER

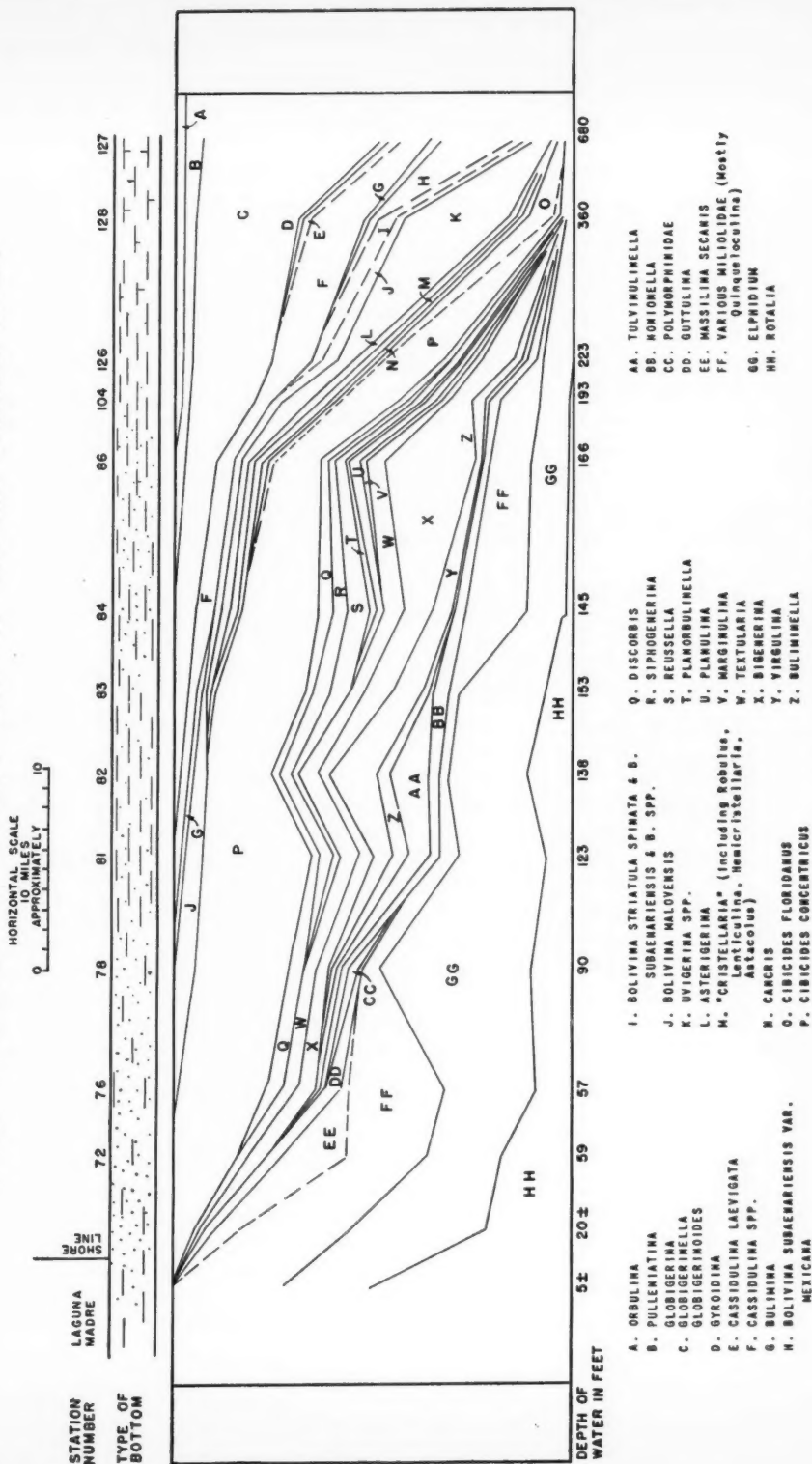


FIG. 17.—Distribution of foraminifera in Gulf of Mexico off Rio Grande.

The results of the investigation of distribution of Recent foraminifera in the Gulf region bear upon this question, and provide the basis for an emphatic negative answer. For example, the waters flowing into Lake Salvador (F, Fig. 11) are fresh, but no single specimen of fresh-water rhizopod was found in several samples from bottom deposits of the lake. Specimens of brackish marsh species are distinct rarities in the shallow waters of the adjacent Gulf, and only one specimen each of fresh-water *Centropyxis* and *Diffugia* has been found in the many marine bottom samples examined near the mouths of the Mississippi River.

In some restricted areas the principal characteristics of the environment appear to have been transported (Fig. 18). Along the quiet, shallow edges of bays where the predominant sedimentary character appears to have been derived from the adjacent marsh, the corresponding marsh faunal assemblage occurs.

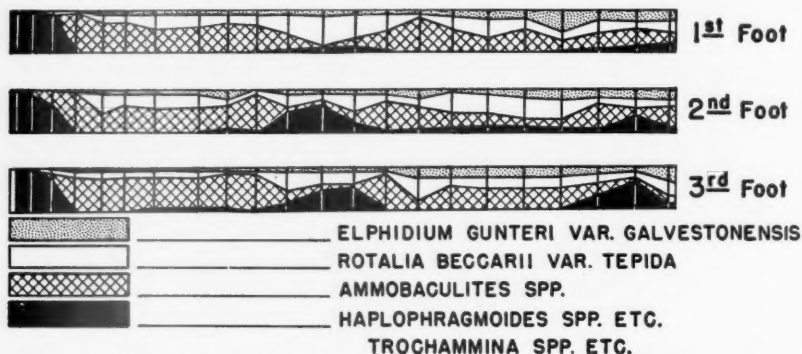


FIG. 18.—Distribution of foraminifera in 3-foot punch cores of Recent sediments. West-east profile across Bay des Islettes, lower Mississippi delta, Louisiana.

Whether the animals live in this derived environment or whether they were transported along with the other detritus makes little difference to the present discussion. There is no question whether shells of recently dead foraminifera are transported *less* far than other sedimentary particles, but only whether they receive significantly wider distribution. Without important exception, it appears that they are not transported in large enough quantities and far enough to destroy their value as relatively precise environmental criteria.

One minor exception to this rule is known, and there may, of course, be others. That exception occurs on beaches, inshore from the wave line, where pelagic detritus is dumped. Mollusks, foraminifera, driftwood, and other trash are piled along a line beyond the waves where chemical action and wind erosion destroy them. On the lower part of the beach, at the strand line, and seaward from it, lives an abundant indigenous fauna controlled by the local environment. There seems to be small probability that the mechanically transported fauna assemblage of the high beach areas would be preserved by burial under ordinary conditions in the Gulf Coast region. It is possible that such preservation could

occur under special conditions as in the case of the foraminiferal sand on the shores of Dogs Bay (Chapman, 1902) near Connemara, Galway, in the British Islands.

METHODS OF EXTENDING BIOFACIES INVESTIGATION TO TERTIARY ROCKS

The faunal interpretation of depositional environment in the Tertiary is based on the assumption that similar faunal assemblages indicate similar environments. This appears to be a useful working hypothesis in the Gulf Coast Tertiary because it produces results that are in harmony with broad-scale stratigraphic relationships in other sedimentary basins.

Individual samples.—Faunal data from the Recent could be applied to an investigation of the Tertiary in several ways. One of these would be the selection of random samples from the Tertiary and computation of the environmental significance of their fossil content on the basis of direct comparison with recent assemblages. When enough data had been gathered, they could be assembled in a space diagram, and the patterns of distribution then compared with other stratigraphic data. This method would appear to be unnecessarily laborious and destined to reversals or failure because of expectable differences between Tertiary and Recent environments and faunas in the Gulf region. There also would be differences in preservation of the fossils and in the induration of the rock, thereby causing differences in the degree of destruction of the more fragile fossils during preparation of material for examination. These and other differences may be expected, in spite of the fact that Recent standards were built up from "fossil" assemblages in the bottom sediments rather than from living assemblages on the surface of the sediments. This was done for the specific purpose of minimizing the difficulties involved in comparing fossil faunas with recent assemblages.

Vertical sections.—A second method would be the analysis of faunal assemblages in a vertical sequence of rocks, and estimation of the environmental significance of each faunally distinctive group of strata by direct comparison with faunal assemblages in the Recent. Various interpretations might be made, such as the alternation of facies within a single vertical section. The comparison of facies units in two or more vertical sections nearly the same in age might produce a basis for interpretation of depositional pattern and slope. Such a method would probably furnish usable results in clear-cut examples. The method would suffer from some of the same defects as individual sample method, in that geographically random Tertiary faunas would be compared directly with Recent faunas. M. C. Isaelsky (1949) has described a valuable technique of correlation by matching levels of maximum transgression.

Single stratum.—A third method would be based on the investigation of the faunal assemblages and other sedimentary characteristics of a thin Tertiary layer, the stratal identity of which could be demonstrated over wide areas up and down the dip and along the strike. This method would be similar to that used in the Recent investigation. Comparisons could be made between Recent patterns

and Tertiary patterns, rather than attempting to place individual Tertiary faunal assemblages in a Recent framework. Additional Tertiary levels could then be investigated similarly and compared with one another as well as with the Recent. This would produce an expanding and strengthening frame of reference.

Geological occurrence.—A fourth method would be the selection of faunas from geologically similar situations and comparison of them with one another and with the Recent. This appears to be an effective variation of the third method and might produce early results in certain limited geological situations such as the character of the boundary of cyclical sedimentary units at various positions on the depositional slopes. In practice, it will be necessary to use the method best suited to the problem at hand.

NEED FOR VERIFIED STRATIGRAPHIC CORRELATION

In all four methods the availability of stratigraphic correlation is assumed. The third method assumes fairly detailed correlations over wide areas. Such correlations are possible at some levels in the Tertiary of the Gulf Coast. These correlations, for the most part, are based on a combination of paleontological data and electric-log characteristics. In view of the fact that the two stated objectives of the coordinated study of Recent and Tertiary foraminifera are to test (1) the character of guide fossils and (2) the environmental significance of fossil assemblages, it seems necessary to re-examine the correlations in a test area on a strictly empirical basis. How, for instance, could we know whether the vertical range of a given guide fossil was controlled by environmental or evolutionary processes, if the stratigraphic correlations, on which the Tertiary phase of the work was based, contained an element of assumption with respect to the evolutionary or the environmental character of that particular guide fossil?

Stratigraphic correlation.—Stratigraphic correlation is directed toward establishing the relationships between sequences of events in separate areas. This is accomplished by three methods: (1) the various techniques of evaluating the probability of stratal continuity; (2) the chronological sequence of faunas; (3) the quantitative evaluation of geological time by means of sedimentary factors, biological factors (growth rings, *et cetera*), and mineralogical factors (disintegration products, *et cetera*). This article deals principally with the first method.

EMPIRICAL METHOD OF MAKING FRAMEWORK OF STRATAL CORRELATION

Local standard sections.—The place to start an empirical investigation of stratal correlation appears to be in a local area where the diversity of the stratigraphic section, and the density of wells, provide a basis for a high degree of probability of correlation, that is, stratal continuity, at least along some beds, or for certain groups of strata. The study begins with the construction of a standard section in one localized area, such as might be provided by a structurally simple oil field with five or ten electric logs, and factual paleontologic data on two or three of the key wells. The network spreads by similar constructions in other

local areas where there is adequate control for making a local standard section. These local standards are then connected by lines along which the probability of correlation may be relatively high or low, depending on many factors such as—distance between fields, number of intervening wildcat wells, distinctiveness of the stratigraphic units, similarity of thickness and facies, consistent rate of change of thickness and facies, total thickness of beds penetrated, structural simplicity or complexity, and other connecting lines. The area of control spreads like a net in which each knot is a local standard section, and each connecting thread adds to the strength of the correlation (Fig. 19).

At the beginning this process is a strictly empirical evaluation of the distribution of facies in a three-dimensional sedimentary mass. No interpretation is made of depositional or post-depositional origin of the features that produce electric log characteristics. No chronological or environmental aspects of either fossils or minerals need to be used, and generally, at this level of investigation, they are not known. This admittedly does not use the information to the full extent, but, by avoiding premature interpretation, it avoids many errors.

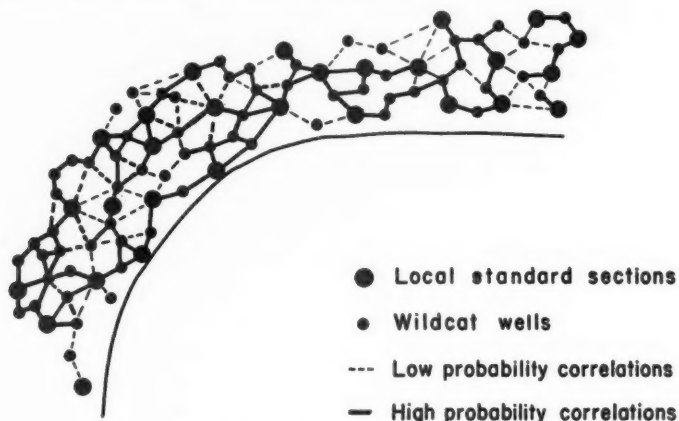


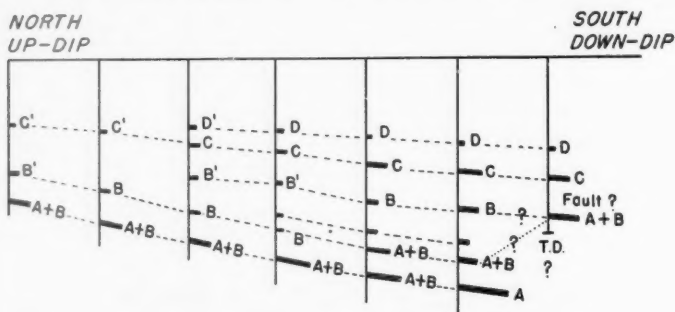
FIG. 19.—Diagrammatic map of correlation network.

During the course of the work, certain bio- or lithofacies criteria are found which have value in identifying locally certain levels in the sedimentary mass, and these are used as stratigraphic guides, particularly in areas of faulting or other structural complexity, but they are used without reference to their theoretical interpretation. Fossil tops are also used as guides where their value can be demonstrated.

Example.—An extreme example would be two electric logs of nearly identical character, located $\frac{1}{4}$ mile apart, 2 miles deep, and penetrating a stratigraphic section of high diversity of distinctive electric-log units; to this might be added complete cores, and for good measure, a diversity of distinctive guide fossils

and faunal assemblages. This example might be extended by the addition of comparable data for unlimited distances in all directions in a region of utmost structural simplicity. The problem of correlation under such circumstances obviously would be one of evaluating agreement and difference of characteristics in adjacent wells, and continuity of facies or rate of change along lines of wells. This seems to reduce to utmost simplicity the method of stratigraphic correlation that has been developed by the use of electric logs and micropaleontology.

Practical difficulties.—In practice the problem is, of course, more intricate. Even in an area of high density of stratigraphic control points, such as the Gulf



Diagrammatic cross section showing climbing of guide species in down-dip (seaward) direction.

A, B, C, D,	—————	GUIDE SPECIES
B', C', D',	—————	DEPAUPERATE VARIANTS
-	—————	VERY SPARSE FAUNA
-	—————	SPARSE FAUNA
—	—————	MEDIUM FAUNA
—	—————	RICH FAUNA
—	—————	VERY RICH FAUNA

FIG. 20.—Diagrammatic cross section showing climbing of guide species in down-dip (seaward) direction.

Coast Tertiary with its estimated 50,000 electric logs and 100,000 paleontological determinations, there are three common situations in which all available data may not be enough. These are: (1) areas with high rate of facies change, (2) long vertical sections of monotonous unfossiliferous facies, (3) structural complications, including local environments produced by contemporaneous structure and deposition. In such situations, distinctive species and key faunal associations or lithologies are useful in proportion to the uniqueness of their character, the restriction of their distribution in the vertical section, and the uniformity and horizontal extent of their development in the area surrounding the problem.

Horizontal extrapolations of such criteria beyond the area of control have been found to be subject to serious error, simply because directional change in the character of the facies may result in a gradational change of the vertical position of the guide fossil in the stratigraphic section (Fig. 20).

TIME-TERMINOLOGY IN STRATIGRAPHIC CORRELATION

Although this network of correlation is based on fine-scale methods (stratal tracing of bio- and lithofacies), it embraces strata that range in age from Paleocene to Quaternary, throughout an area of 100,000 square miles, with an average depth of penetration of nearly 2 miles and with a range of facies from continental to bathyal. No use has been made of time-terminology in the description of this fine-scale network. Care has been used to avoid reference to evolutionary paleontological zonation, radioactive disintegration products, or other rock characteristics which are linked by ulterior considerations to time concepts. Superposition has not been stated in terms of chronology, or lateral continuity in terms of synchrony. Therefore, since the network is not referred to time, it may serve as a stratigraphic reference for considering the value of time concepts in classifying the strata.

The greater part of presently available stratigraphic information on the Gulf Coast has been accumulated in the past 25 years. But there were several decades of geological exploration that antedated this volume of data. Much geological language is inherited from that earlier period, and present thinking is affected by that language. For instance, not one of the named surface or subsurface units includes all the members of a cyclical sedimentary unit, although the cyclical units appear to represent the most basic generalization of Gulf Coast stratigraphy. On the other hand, the grosser faunal realities are bracketed into groups such as Midway (Paleocene), Wilcox, Claiborne, Jackson (Eocene), and Vicksburg (Oligocene). These are invested by many geologists with time significance. It is common to speak of "sediments deposited during Claiborne time" rather than "sediments containing Claiborne fauna." The same habit of expression occurs with respect to the use of "time-planes" or "time-units" in fine-scale correlation.

From the viewpoint of stratigraphic correlation in the Upper Tertiary of the Gulf Coast there appear to be three major criticisms of the use of time-terms in precise stratigraphic correlation. In the first place, such terms can be replaced by factual statements of the criteria used. Since time-terms are used in the place of factual statements (such as descriptions of key beds, fossil zones, fauna succession, or cyclical sedimentary units), they appear to be not only unnecessary but also harmful, by reason of the tendency to suppress essential facts.

In the second place, time-terms imply an absolute and proved relationship, whereas in most instances the data justify no more than judgments of probability. Therefore, it seems to follow logically that the use of time-terms, in the place of (or in addition to) stratigraphic terms of faunal or lithologic relationship, would tend to crystallize judgment, and thereby tend to close the mind to further investigation or analysis.

QUALITATIVE CHRONOLOGY Expressed in terms of STRATIGRAPHIC SEQUENCE

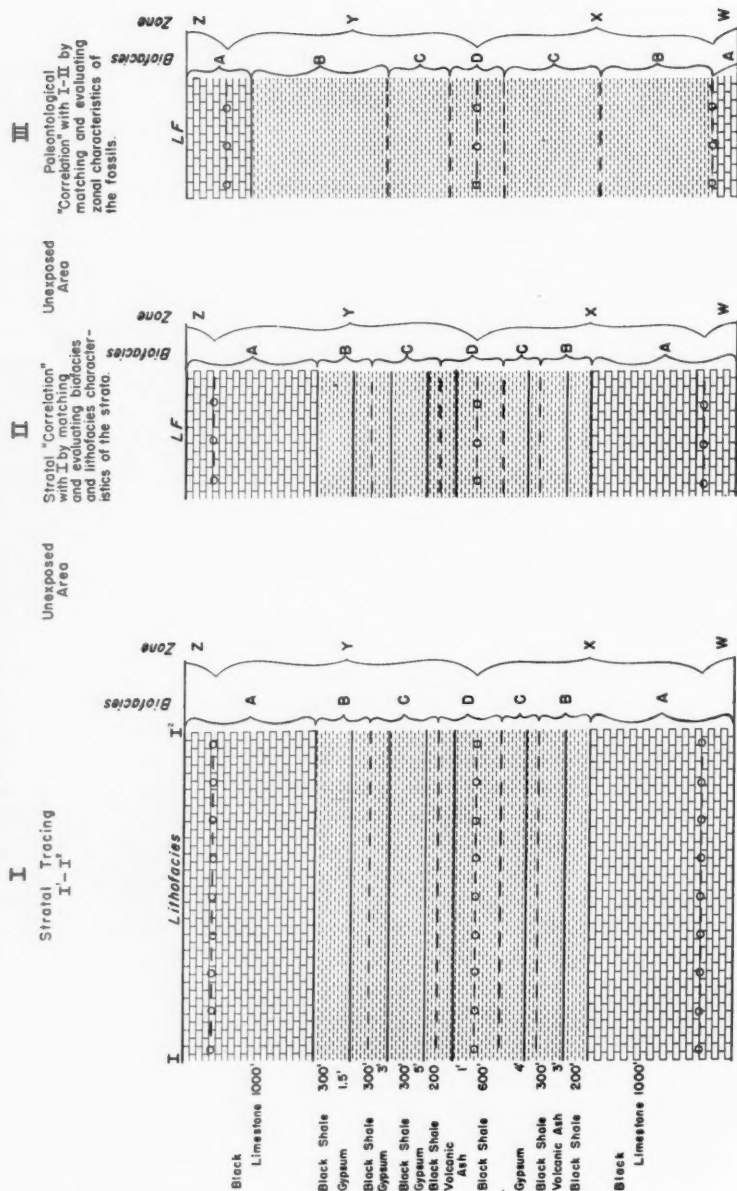


FIG. 21.—Qualitative chronology expressed in terms of stratigraphic sequence.

In the third place the word "time" appears to be used for several different concepts. These different concepts may be divided first into pure idealizations, and second into chronological relationships deduced from observed facts. The first class includes such concepts as "time-planes" and "time-units." In their idealized form these are generally considered as surrounding the globe by concentric planes and sheaths. Clearly, any specific period of time existed all around the globe but it also existed all through the globe and everywhere else. Time is not defined by space but by duration; and it is measured by sequences of events. Consider the case of a time-plane in a sequence of strata, assuming for the moment that it could be identified as a time-plane. When these strata are deformed the time-plane is deformed. When the strata are overturned the time-plane is overturned. When the strata are brecciated the time-plane is brecciated. The time-plane has no existence, no individuality, no reality apart from the events by which it is defined. Time-planes do not define strata. Stratigraphic time is defined by the sequence of stratigraphic events. How then, can time-planes add to the analysis of a stratigraphic problem when they are themselves defined by the end result?

The second category of time concepts can be subdivided into qualitative and quantitative chronologies which are illustrated diagrammatically in Figures 21 and 22. The qualitative chronologies are based on observed superposition and are expressed in terms of stratigraphic sequence. A hypothetical example is used for the purpose of representing a set of conditions that are most favorable to a consideration of "time-classification" in stratigraphy. Figure 21-I is a diagram of a hypothetical sequence of strata completely exposed for a number of miles along strike. The boundaries of the sedimentary bio- and lithofacies parallel the key beds and the fossil zones. For the sake of the argument, the fossil zones, in this instance, are assumed to be based on faunal characteristics, which are the result of evolutionary processes. Figure 21-II is assumed to be separated from 21-I by a covered area several miles in extent. Sedimentary facies, lithological key beds, and fossil zones are assumed to occur at 21-II in the same sequence, with the same characteristics and with the same intervals separating them, as those which occur at I. Evaluation of stratal continuity between II and I is based on evaluation and matching of the faunal and lithologic characteristics.

Figure 21-III represents an area separated from I and II by many miles of unexposed strata. The gross sedimentary bio- and lithofacies at III are the same as some of those at I and II but they occur in different thicknesses. The key beds of I and II are not present at III, and stratal equivalence can not be demonstrated by matching facies characteristics. However, the probability of faunal continuity between III and II or III and I can be evaluated from the presence of the fossil zones w, x, y, and z which are assumed to be the same in all three areas.

In this stratigraphic analysis there is no absolute time (time-planes) or quantitative time (measured in years). The only valid time reference seems to be

the inference of relative geological age which is based on observed superposition and the observed manner of deposition of stratified sediments.

It might be argued by advocates of time-terminology that the objective of fine-scale stratal correlation is to establish planes of synchrony between two or more areas. This appears to be the "time-plane" under another name. However, the question of synchrony of stratal and faunal units probably contains the es-

'QUANTITATIVE CHRONOLOGY
Expressed in "Years"

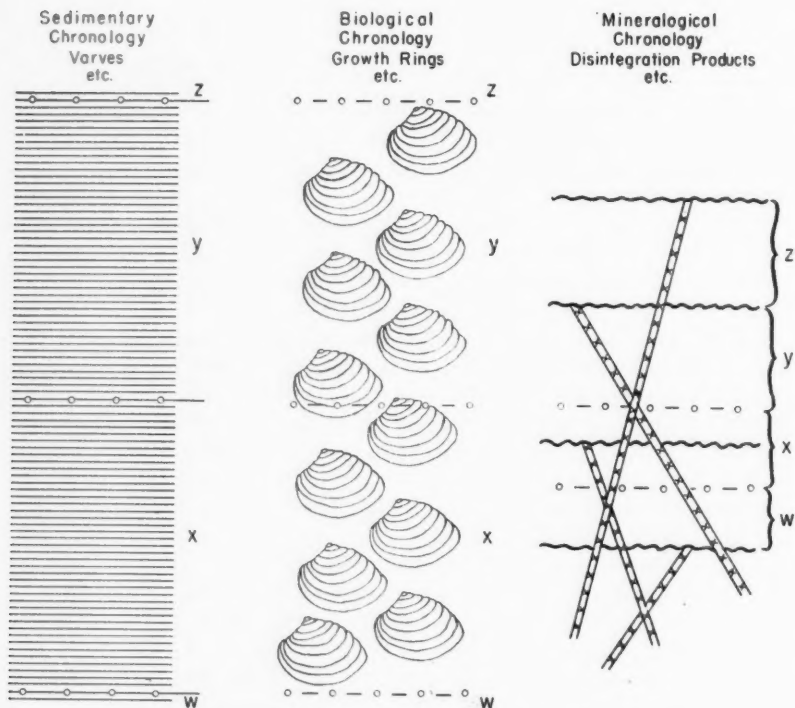


FIG. 22.—Quantitative chronology expressed in terms of years.

sence of the "time-plane" thesis and it can not be dismissed lightly. Stratigraphers seldom see more than a small fraction of the total evidence. In subsurface stratigraphy, it is about one part in 9 million in oil fields with a 40-acre spacing, and one part in 1,300 million in wildcat territory with four test wells to a township (the calculations being based on bore holes 6 inches in diameter). The stratigrapher simply has to use imagination and ulterior considerations, drawn from his experience, to fill the gaps. The strata we think about are usually mental

reconstructions based on our fragmentary data, but it is difficult to see how it helps matters to endow these concepts with attributes, such as time-plane boundaries, which can not be measured at any locality, and hence can form no part of the objective evaluation of the data.

There are many common English words which are used to describe the relationships of events to time. Two of these seem to be particularly suitable to the present discussion. They are *synchronous*, which refers to occurrences at the same time or during the same (usually brief) periods of time; and *contemporaneous*, which refers to events or sequences of events that occurred at nearly the same gross intervals of time, usually measured in terms of years. In this sense, it appears that *contemporaneity* might be used to describe geological occurrences of which the time values had been established quantitatively, that is, in terms of years. Quantitative chronology as used here is based on the measurements of rock properties that are similar to those which have been observed to be formed during specific increments of astronomical time, that is to say, during a specific number of years. These properties are sedimentary (for example, varves), biological (growth rings), and mineralogical (radioactive disintegration products). They are illustrated in Figure 22 by hypothetical examples. None of these classes of data has been used to any considerable extent in computing the age of the Gulf Coast Tertiary so far as known to the writer, but future technological developments may make them valuable tools for that area.

Sedimentary characteristics have been used primarily in building a chronology of parts of the Pleistocene. The method may have wider utility, in view of the banded character of marine sediments in some areas such as the Gulf of California and such well known geological examples as the Green River shales of Wyoming. Biological characteristics are added mainly for completeness but seem to offer promise under specialized conditions. Mineralogical criteria are illustrated by single members of four different dike systems, each of which is truncated by a different unconformity. The geologic age of each of the dike systems is not known exactly but is delimited by the beds above and below the respective unconformities. This method may be supplemented by the use of uranium disintegration products in black shale or by other mineral disintegration products in sedimentary rocks.

It seems probable that dating of geological events may be greatly improved in the next few years. It seems desirable, therefore, to reserve time-terms in stratigraphy for quantitative units of astronomical time, and to express relative geological age in terms of stratigraphic data, namely, lithologic and faunal succession. Following the same line of reasoning, stratigraphic correlation can also be expressed in terms of stratigraphic fact, namely, stratal or faunal continuity.

FACIES CHARACTER OF FORMATIONS AND THEIR CYCLICAL PATTERN

Alternation of sand and shale formations.—Large-scale alternations of shale and sand formations in the vertical succession are very helpful in tracing strata

in the subsurface by the network method in the Tertiary of the Gulf Coast. Some of these are well defined both in the subsurface and at the outcrop where they are given formational names. The most clearly expressed alternating units in the Tertiary occur in the Claiborne (middle Eocene) which may serve as an example (Fig. 23). At the outcrop in Louisiana, the Claiborne group is composed of four formations which, in ascending order, are Cane River shale, Sparta sand, Crockett shale, and Yegua sand. The Cane River, which rests on the Wilcox group, is richly fossiliferous marl and clay in its lower part. The upper Cane River is less fossiliferous, silty and sandy shale. The overlying Sparta is mostly sand with

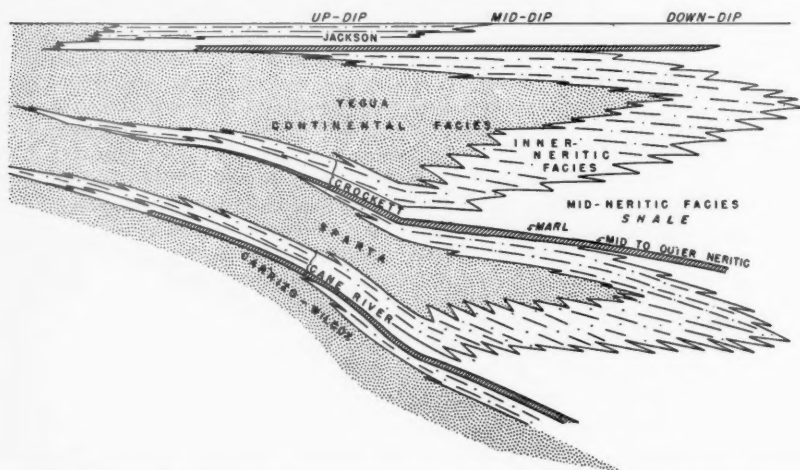


FIG. 23.—Stratigraphic diagram of Claiborne group (Eocene), showing cyclical sedimentary units in Cane River-Sparta and Crockett-Yegua. Central Louisiana partly after H. N. Fisk (1940).

thin, sparsely fossiliferous clay and silt layers. The same succession is repeated in the Crockett and Yegua, the Yegua being overlain by clays of the Jackson group. Within these formational units are thinner alternations in the bio- and lithofacies. Some of these are thick enough and of wide enough extent to be given member names, such as the Moodys Branch marl in the lower Jackson.

The Claiborne formation thins toward the east, and the grain size gradually decreases until, in peninsular Florida, the entire Claiborne is limestone (Fig. 24). On the west and southwest along the present strike, the Claiborne formations become coarser-grained. These changes are very gradual and take place over hundreds of miles. In a downdip direction, toward the present Gulf, major facies changes take place within 50 miles or so. The sand, in a gulfward direction, becomes finer-grained and gives way to fossiliferous shale. The shale formations also lose the sandy character in their upper part, and the over-all section thickens and becomes more fossiliferous.

Interpretation of sedimentary character in terms of depositional environment.—

Claiborne (middle Eocene).—These gross lithologic changes, including kind and amount of fossil content, indicate that the depositional slope for the Louisiana Claiborne was toward the south. The changes toward Florida indicate decreased turbidity. Comparison of the Claiborne faunal assemblages with assemblages in the Recent supports these indications. The faunal assemblages in the lower Cane River and the lower Crockett at the outcrop are most similar to mid-neritic (mid-continental shelf) assemblages in the Recent. Upper Cane River and upper Crockett faunal assemblages are most nearly like those in the inner neritic. The

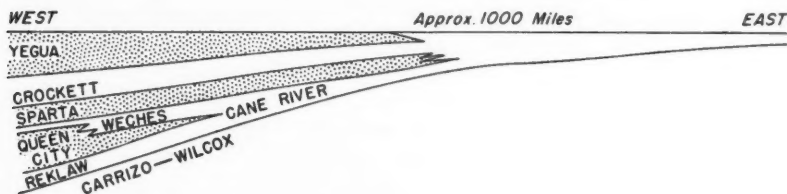


FIG. 24.—Stratigraphic diagram of Claiborne group along strike from Texas to Louisiana.

Sparta and Yegua sands are, for the most part, non-fossiliferous, but they contain thin beds of silty shale with assemblages that are grossly similar to those found in brackish environments in the Recent.

Seaward, the stratigraphic equivalents of all four formations contain faunas that indicate deeper-water conditions than those at the outcrop. Thus, the down-dip (seaward) equivalent of the Sparta is fossiliferous sandy shale with a fauna and a lithologic character like the upper Cane River at the outcrop. In like manner the bio- and lithofacies of the upper part of the Cane River shale in the more down-dip (seaward) area of the subsurface resemble those in the lower part of the Cane River at the outcrop. The lower Cane River in the subsurface contains deeper-water faunas than those at the outcrop, and it rests on brackish to shallow marine equivalents of the Carrizo-Wilcox (Fig. 23) (Echols and Malkin, 1948).

The facies distribution, as described, indicates that the formational couplet composed of Cane River and Sparta is a cyclical sedimentary unit in which the transgression of the Cane River over the Carrizo-Wilcox is relatively abrupt and reaches its maximum in the lower part of the Cane River. The following regressive phase is comparatively thick and gradational, extending through the upper Cane River and Sparta (Fig. 23). The minor alternations of facies in both the transgressive and regressive phases contain faunas which suggest alternating depth of water. The main transgressions and regressions, therefore, appear to have been oscillatory.

The distribution of facies in the Crockett-Yegua and in the Midway-Wilcox shows that they form cyclical sedimentary units similar to the Cane River-Sparta.

Upper Tertiary.—The Upper Tertiary appears to have been deposited under

cyclical conditions similar to those in the Claiborne. However, the Upper Tertiary units are not as clearly defined as those in the Claiborne, possibly due to greatly increased rate of deposition (the Upper Tertiary cycles are several times as thick on the average as those in the Claiborne), and to greatly decreased area of deposition normal to the axis of maximum sedimentation (the belt of Upper Tertiary rock is perhaps half as wide as the corresponding depositional belt in the Claiborne). The result of greater thickness, and decreased areal extent in the Upper Tertiary, is rapid changes of facies, particularly along those belts of flexure where the greatest thickening occurs.

The upper Catahoula cyclical unit is the most clearly expressed and the best known in the Upper Tertiary (Fig. 3). At the outcrop, which appears to be near the feather-edge of the unit, it is composed of a few hundred feet of non-fossiliferous (assumably continental) sand and shale. In the extreme downdip part of its known subsurface occurrence, it is more than 5,000 feet thick and is composed of the following units in ascending order: Anahuac (predominantly shale) and Catahoula (predominantly sand). The Anahuac is subdivided into the *Marginulina* zone (at the bottom), *Heterostegina* zone (in the middle), and *Discorbis* zone (at the top). The *Marginulina* zone is somewhat less sandy and more fossiliferous than the underlying Frio and represents slight transgression. The *Heterostegina* zone rests with sharp facies break on the *Marginulina* zone and extends as a recognizable marine facies about 30 miles farther landward. The *Heterostegina* zone transgression corresponds with the transgression at the base of the Cane River marl, Crockett marl, and Moodys Branch marl (Jackson) in the Eocene (Fig. 23). The upper *Heterostegina* zone appears to have been deposited under conditions of oscillatory regression which continued into the shaly lower parts of the *Discorbis* zone, then into the sandy upper part of the *Discorbis* zone and finally into the predominantly sandy beds of the upper Catahoula.

The general depositional cycle in the Anahuac-upper Catahoula is similar to that described for the Claiborne cyclical units and it emphasizes the initial, slightly transgressive unit (*Marginulina* zone) that precedes the main transgressive pulse in the basal *Heterostegina*. The *Marginulina* zone is lithologically more similar to the underlying Frio, and is classed with it in some areas under the term "*Marginulina*-Frio." The fauna of the *Marginulina* zone, however, is more closely related to that of the *Heterostegina* zone, indicating that if there is either a hiatus or a period of accelerated evolution, it occurs between the Frio and the *Marginulina* zone.

Cyclical pattern of Gulf Coast Tertiary.—The major cyclical sedimentary units in the Tertiary of the Gulf Coast are differentiated by five recognizable divisions. These are, in ascending order: (a) a transitional transgressive member (*Marginulina* zone of the Anahuac and *Nonionella cockfieldensis* beds of the Claiborne-Jackson are the thickest and best known units of the class); (b) rapid transgression, slow deposition, and tendency for the limestone province of the eastern Gulf region to invade the clastic western province (lower Midway marl, Cane River marl, Weches marl, Crockett marl, Moodys Branch marl, Vicksburg lime-

stone, and *Heterostegina* limestone); (c) the gradual but oscillatory change to regressive conditions in the upper part of the shale members; (d) a relatively sharp change to less fossiliferous shales and sands which also show the effects of oscillatory regression; (e) another relatively abrupt change to continental sands.

The sedimentation was apparently continuous, and there are many possible levels at which the boundaries of the cycles might be placed. The most natural boundary on the Gulf Coast appears at the base of the initial transgressive member, which level corresponds with the main faunal break.

Table III shows a correlation of the formation-like divisions of Gulf Coast cyclical sedimentary units with the divisions of similar units in the Pennsylvanian of the Illinois and Ohio coal basins as listed by Weller (1930).

In Illinois, a prominent unconformity is developed between the main sand member and the underlying shale of most cyclical units. It is convenient, therefore, to use that level as the cyclical boundary in Illinois, even though it is recognized that more time may have elapsed during the formation of the fire clay than is represented in the hiatus at the unconformity.

Another difference between the Illinois and Gulf Coast cyclical units lies in their thickness; those in the Tertiary range from 200 to 13,000 feet thick while some of the Pennsylvanian cycles are recognizable where they are only a few feet thick (Wanless and Weller, 1932). The stratigraphic equivalents of the Pennsylvanian cyclical units of Illinois that occur in the geosynclines of Arkansas and Oklahoma probably have thicknesses more nearly comparable with those observed for the geosynclinal Gulf Coast Tertiary.

It is particularly noteworthy that the tectonic setting of the depositional environment is very different for the Pennsylvanian of Illinois and the Tertiary of the Gulf Coast. Yet the sedimentary rhythms are similar. This seems to support the hypothesis that these rhythms are the result (primarily) of processes that operate in the source area.

Seven major cyclical units can be discerned in the Tertiary and one in the Quaternary of the Texas and Louisiana Gulf Coast. These are shown in Table IV.

FACIES ASPECT OF FOSSIL ZONES⁵

Multiple character of fossils in sedimentary rocks.—It is easy to forget that fossils have several distinct uses in work with sedimentary rocks. They are, in their present state, inorganic particles. As such, they must be taken into account in various sedimentary and mineralogical analyses. In their inorganic role, they also serve as distinctively shaped sedimentary particles which can be used to identify a specific stratum or group of strata within a specified area of control, totally irrespective of any biological implication. As stated previously, such a procedure does not make full use of the fossils, but it is desirable in the early stages of some investigations in order to avoid premature interpretation.

⁵ Teilzone, epibole, and faunizone as summarized by W. J. Arkell (1933). Biozone is not included in this discussion except where specified.

TABLE III

Gulf Coast Tertiary*		Illinois-Ohio Pennsylvanian	
Not represented	3	Continental	
c Sand and shale	2	Underclay	
d Shale and sand	1	Sandy and micaceous shale	
		Sandstone	
		Unconformity	
		Marine	
c Shale	8	Shale	
b Limestone and marl	6 and 7	Limestone and calcareous shale	
a Sand and shale	4 and 5	Coal and black fissile shale	

* The divisions of the Gulf Coast Tertiary cyclical unit are listed for the typical, mid-dip development. The relative amounts of sand and shale vary greatly at different places on the depositional slope.

TABLE IV

GULF COAST CENOZOIC SEDIMENTARY CYCLICAL UNITS

Age	Transgressive Phase	Regressive Phase	Order of Magnitude in Down-dip Areas (Feet)	See Note
Recent and Pleistocene	Lower part of Pleistocene	Recent and upper part of Pleistocene	3,500	1
Pliocene and Miocene	Lower Fleming	Upper Fleming	13,000	2
Upper Oligocene	Lower and Middle Anahuac*	Upper Anahuac and Catahoula (uppermost Catahoula of outcrop)	5,000	3
Oligocene and Upper Eocene	Vicksburg and Jackson	Frio*	10,000	4
Upper Eocene	Lower Jackson	Middle Jackson	2,000	5
Middle Eocene	Lower and Middle Crockett	Upper Crockett and Yegua	3,000	6
Middle Eocene	Lower Cane River	Upper Cane River and Sparta	4,000	7
Lower Eocene and Paleocene	Lower Midway	Upper Midway and Wilcox	10,000	8

* The Frio and Anahuac formations are regarded as Miocene in age by some authors.

Notes:

1. The major features of the cyclical development in the Pleistocene, as seen in the subsurface, appear to have been produced by processes similar to those which produced the Tertiary units, rather than by major changes in sea-level, such as may have been related to glaciation. The Quaternary cyclical unit appears to be in its regressive phase.

2. A composite of maximum thicknesses of each of the units would be nearer 15,000 feet, possibly more.

3. The regressive phase contains two fairly large-scale alternations of facies which resemble two-phase (Bornhauser, 1947) cyclical units.

4. The Frio contains three or more large-scale alternations of facies that in some limited areas resemble two-phase cyclical units. The *Marginulina cocoensis* beds of the upper Jackson appear to be the initial transgressive phase of the Vicksburg-Frio cyclical unit.

5. The *Textularia hochleyensis* zone appears to be the regressive phase of the Jackson cyclical unit. The *Nonionella cockfieldensis* beds (so-called uppermost Yegua of the subsurface) contain a Jackson fauna and appear to be the initial transgressive member of the Jackson cyclical unit.

6. The *Discocyclina* marl appears to be the time of widest transgression and clearest-water deposition in this cyclical unit.

7. The Cane River shale in Texas is divided into Weches shale (above) and Reklaw shale (below) with the Queen City sand between. This relationship appears to contain another cyclical unit, particularly if one considers the beds below the *Discocyclina advena* marl of Weches as an initial transgressive phase similar to the *Marginulina* zone of the Anahuac or the *Nonionella cockfieldensis* beds of the Yegua-Jackson boundary complex. The Carrizo of Texas (upper Wilcox of Louisiana) is probably another of these initial transgressive phases.

8. The Nanafalia-Tusahoma, and Bashi-Hatchetigbee of Alabama may represent two-phase cyclical units that are not discernible so clearly in the sand and sandy shale deposits of the Wilcox group of Texas.

Fossils can also be used in their biological role in making interpretations of depositional environments and age relationships. In making such interpretations, it is necessary to consider the two sets of processes that combine to produce the distribution of fossils in the sedimentary mass. One of these sets is operative in the environment of deposition; the other set, grouped under the term "evolution," operates through time.

It was generally supposed, before the days of electric logs, that evolutionary factors were predominant in the zonal distribution of fossil assemblages and guide fossils in the Gulf Coast Tertiary. However, with the increased density and precision of stratigraphic control, by the combined use of electric logs and micropaleontology, it can now be demonstrated, in most instances, that the precise top levels at which guide species occur, as well as the precise top level of their associated faunas, correspond with facies boundaries. Their patterns of distribution follow facies patterns. Therefore, it now appears that in the rapidly deposited, horizontally variable, Upper Tertiary of the Gulf Coast, the formations and fossil zones are the lithological and faunal aspects of the same phenomena.

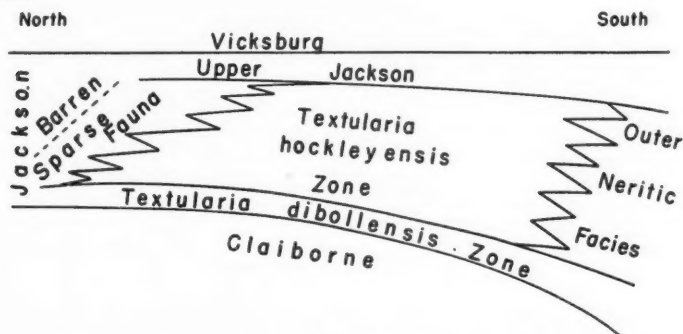


FIG. 25.—Diagrammatic cross section of *Textularia hockleyensis* zone, showing horizontal and vertical distribution in direction of depositional slope.

Examples of zones and special features of faunal distribution.—*Textularia hockleyensis* zone.—The upper boundary of some zones, like the upper boundary of some formations, occurs at different stratigraphic levels in different areas. It is the rule that most zonal tops occur at progressively lower levels shoreward from their facies belt of maximum utility. The *Textularia hockleyensis* zone in the upper Eocene is a widely known example (Fig. 25). The zonal criteria of this stratigraphic unit are also absent seaward where deeper-water conditions support a different faunal assemblage.

Heterostegina zone.—Another well known example is the *Heterostegina* zone, which maintains a relatively constant stratigraphic level throughout wide areas in the mid-neritic and inner-neritic deposits (Fig. 3). However, seaward, the zonal assemblage occurs several hundred feet higher in the section. Still farther

seaward in deeper-water (bathyal) equivalents, all of the guide fossils of the neritic *Heterostegina* zone are wanting, and correlation between the neritic and bathyal equivalents rests on a narrow area where the two major facies are interbedded

Horizontal and vertical restriction of guide fossils.—It appears to be a principle that those species and variants which are most useful in zonation are sharply limited in their horizontal distribution, particularly in the direction of maximum facies change (Fig. 26). Furthermore, those species which resemble them most closely in the Recent are those which occupy narrow environmental belts and are assumably ill adapted to environmental change. Stratigraphically long range species, on the other hand, have wide horizontal distribution in the Ter-

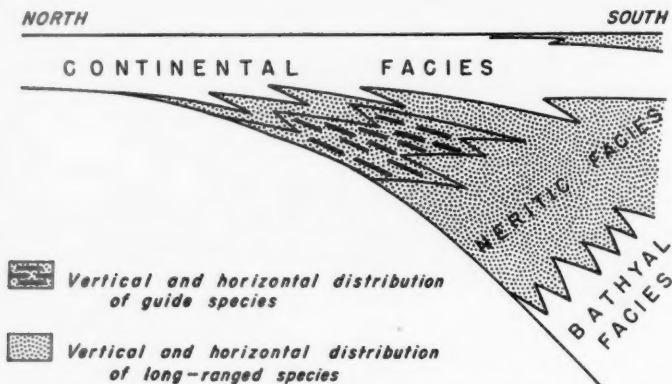


FIG. 26.—Diagrammatic cross section of cyclical sedimentary unit, showing distribution of long-ranging and guide species.

tiary, and they resemble the species in the Recent which appear to have a wide range of environmental tolerance.

Thin stratigraphic units with distinctive faunal assemblages.—There are, of course, many thin stratigraphic units characterized by faunal assemblages which can be shown to have great value in local or even subregional correlation (Fig. 27). These units also, without exception, are subject to environmental controls in their horizontal extent. There is a strong presumption that their vertical limits also are controlled by environmental factors. The net result is that this class of so-called zonal criteria can be used in those areas where they have been shown to be usable. Their value is demonstrated by their agreement with the over-all stratigraphic network of which they form an integral part on an empirical basis.

Examples of apparent evolutionary tops of vertical ranges.—There are other classes of paleontological phenomena, which apparently are produced by evolution and may be usable as independent checks on facies network correlation. The method of delineating them among the smaller foraminifera is exhaustive (Lowman, 1947, p. 89).

An example of this class of evidence is the *Bolivina perca* "strain" which is first recognizable in the Frio. The principal variants of *B. perca* in the Frio, in the *Marginulina* zone, and in the lower and middle *Heterostegina* zone differ one from another, by characteristics which may be due to environmental controls. However, in the upper-middle part of the *Heterostegina* zone, *B. perca* is very elongate, and at slightly higher levels it has terminal spines on each chamber. The spinose variant of *B. perca* appears, from scanty data, to occupy a thin stratigraphic interval. However, its facies belt of distribution is so narrow (possibly due to decreased biotic potential) that its precise stratigraphic range has not been demonstrated. The development of the elongate and spinose variants of *B. perca* appear to be evolutionary, and this particular line of *perca* ends with the

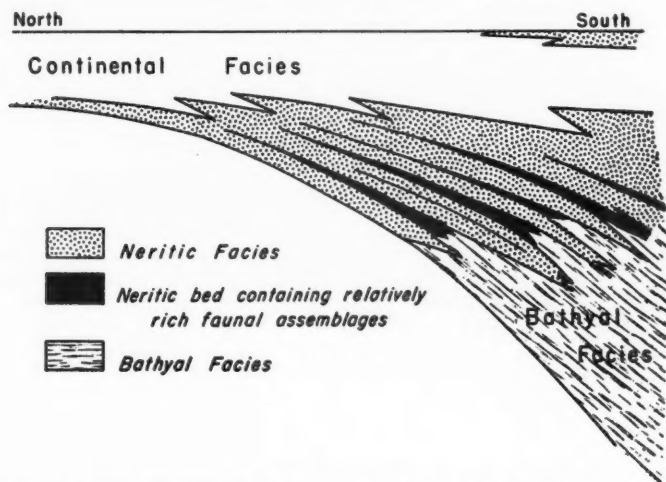


FIG. 27.—Diagrammatic cross section of cyclical sedimentary unit, showing distribution of richly fossiliferous streaks (black) in neritic facies.

spinose variant. Whether environmental processes played a part in its final extinction has not been ascertained.

Biozone versus teilzone.—Fossil variants of the kind just described may have upper limits of their vertical ranges that were produced by processes that were not directly related to facies. If enough work were done on this class of evidence, it might provide an independent check on facies correlation. But in the absence of evidence of this general class, it appears to be unsafe to assume that the top range of a variant, even if stratigraphically constant over wide areas, coincides with the top of its biozone, that is, the top of its total, world-wide occurrence.

The vertical ranges of many species and variants of both large and small foraminifera are restricted to one sedimentary cycle. Some of them like *Textularia hockleyensis* have such a consistent stratigraphic level at which they "top," over such a wide area, that some cause other than facies seems to be indicated. How-

ever, in the absence of evidence within the species, such as demonstrable evolutionary stages, the stratigraphic evidence alone proves only a stratigraphic condition. Furthermore, the mere absence of a demonstrable facies change at the critical horizon may be due only to inability to read in the rock the records of climatic or other environmental changes. A practical consideration is far more weighty than these theoretical ones, namely, that many guide species which have been observed to maintain stratigraphically consistent "tops" over wide areas have been found in other areas to range higher or lower in the section (Fig. 20). So far as the Upper Cenozoic of the Gulf Coast is concerned, it appears that the biozone (total, world-wide range of a species) is a biological concept of little value in precise stratigraphic correlation.

Paleontological zonation (including biozone) in stratigraphic vacuum.—It is interesting to speculate on the method that might be used in attempting to discover the time relationships of totally new assemblages of fossils from uncorrelated localities, in none of which more than a few feet of the stratigraphic succession were exposed. C. B. Schultz and T. M. Stout (1948) recently commented on this type of situation.

A systematic stratigraphic and regional approach to the study of fossil mammals of the Medial to Late Tertiary and Pleistocene of North America is relatively new, because the early workers felt that the specimens themselves were adequate without any other data to show the vertical changes and to demonstrate the "evolution" in which they were primarily interested The old dictum, "There is no evolution in the Pleistocene," has been proved wrong, but the basis for the concept was confusion produced by mixed faunas and inadequate stratigraphic data.

The point seems to be that stratal correlation is essential to establishing paleontological standards whether on a fine or coarse scale and whether regional or local. This precept or principle appears to apply with full force to the Gulf Coast late Tertiary.

"Total section" in one vertical section versus reconstructed total vertical section composed of similar facies units in different areas.—The "total stratigraphic section" is another paleontological ideal which seems to apply to the Upper Tertiary of the Gulf Coast only with modification. Theoretically, the proper place to establish paleontological zonation (including biozone) is in an area where all parts of the section to be zoned are present in the same facies (R. M. Kleinpell, 1938). Such a condition is not known for any sedimentary cyclical unit at any locality in the Upper Tertiary of the Gulf Coast. Due to the regressive character of the greater part of the stratigraphic section, such a standard total section in the same facies must be composed of units of equivalent facies and of different ages at different places (Figs. 28 and 29).

The zonation that is established in any vertical section containing several facies, such as levels I to V at locality 1 (Fig. 28), will be the combined product of evolution and environment. The net result will be a vertical sequence of partial zones (teilzones). What might be called the total (biological, or evolutionary, or

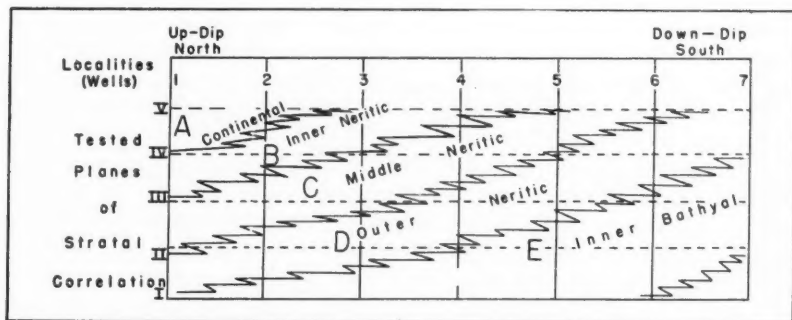


FIG. 28.—Diagram illustrating change in stratigraphic position of biofacies in down-dip (seaward) direction.

true) zonation can be made only after the correlations are known, and the facies equivalence at various stratigraphic levels has been established. Whether this can ever be done in a sequence like the Gulf Coast Upper Tertiary is open to doubt because facies changes, such as changes in turbidity, that are prominent in the development of cycles, persist horizontally up and down the depositional slope across major environmental belts, thereby blanking out the development of a particular combination of depth-plus-turbidity at a particular level. Therefore, Fig-

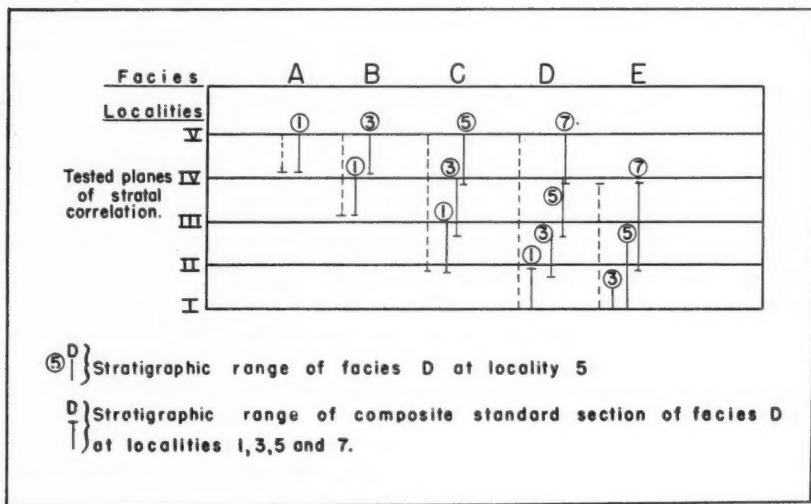


FIG. 29.—Construction of equivalent-facies total section (isobiofacies) for biozonation. Extending this construction beyond limits of diagram, it is theoretically possible to obtain complete isobiofacies total sections for all five facies, extending through stratigraphic units I through V.

ures 24 and 25 probably illustrate an unattainable ideal of equivalent-facies (isobiolithofacies) total section that would be needed to establish a total zonation. It seems probable, therefore, that the present partial zonation (teilzonation) which has been developed on the Gulf Coast over the last 25 years, is well adapted to the regional conditions.

Value of guide fossils in Upper Tertiary of Gulf Coast.—In order to avoid possible misunderstanding, it should be stated that there are many species of foraminifera in the Gulf Coast Tertiary which are extremely useful in identifying specific stratigraphic levels within known parts of the region. Some of these, like *Textularia hockleyensis*, have been proved very helpful in making precise stratal correlation throughout a strike belt, possibly 70 miles wide and 700 miles long, —not that the top range of *Textularia hockleyensis* has been proved to mark the same precise stratigraphic level from Mexico to Alabama, but rather that its value in precise correlation has been demonstrated by the network method in local and subregional areas throughout its strike belt of greatest utility within that province. There are many other species with narrower and shorter geographic belts of consistent stratigraphic occurrence within which they have been shown to be pre-eminently useful in identifying specific levels, thereby furnishing a basis for estimates of depth to objective sands and other stratigraphic information. But it should be reiterated that there is no proof that any of these precise fossil ranges is equivalent to the top of its biozone or, on the contrary, that it was not produced by regional or subregional changes of environment. For example, the top of the *Textularia hockleyensis* zone is overlain by deeper-water deposits of the upper Jackson.

Relative age identification by fossils.—There is another class of stratigraphic problem in which paleontological data are used in an entirely different way. To this class belong those stratigraphic sections in which stratal correlation with near-by standards is lost in a well below a specific depth. In some instances stratal correlation can be re-established at a lower depth, with or without the help of guide fossils or faunal associations. In others, stratal correlation can not be re-established because paleontological and other criteria are inadequate. But in still other instances, stratal correlation can not be established even though the fossils are adequate to give a relative age determination. For example, a well drilling in the *Heterostegina* zone (middle Anahuac formation-upper Oligocene⁶) “loses correlation” with near-by wells that are being used as standards of comparison. The fauna of the beds below the last correlative stratal unit contain species that are restricted to the Frio (Oligocene)⁶. No exact correlation with any particular bed in the Frio may be possible, but the absence of the *Marginulina* zone (lower Anahuac) is demonstrated. This kind of paleontological correlation involves only the relative chronological sequence of species or genera, and its use must be guided by other considerations than those outlined in this paper. It belongs to the general class of paleontological evaluations that are used in making

⁶ The Frio and Anahuac formations are regarded as Miocene in age by some authors.

correlations between separate sedimentary basins or between continents. It is mentioned here only to avoid possible misunderstanding, by those who are unfamiliar with the region, as to the diversified value of paleontological criteria in the Gulf Coast Tertiary.

SEDIMENTATION IN OTHER REGIONS

The foregoing description of the facies characteristics of formations and zones has been restricted to the Gulf Coast Tertiary because that is the body of rock under discussion.

There has been no intent to imply that either the facies patterns or the methods used to decipher them are restricted to the Gulf Coast Tertiary. Empirical network correlations have been developed independently in many other areas. Differing degrees of emphasis are placed on electric logs, lithologic logs, and faunal identification, according to the rate of facies change, thickness of strata, and density of control points. The network method of correlation seems to the writer to be essentially the method of subsurface correlation which is sound in both theory and practice, and which is bringing wide sedimentary provinces within increasingly precise stratigraphic control. R. S. Allan (1948) has challenged the validity of the empirical methods of oil-company stratigraphers and micropaleontologists. This seems to be due to misapprehension, because Allan proceeds, in the same article, to advocate the use of essential parts of the system he criticizes. Allan also advocates the use of biozones in stratigraphic correlation. However, biozones can not be established in the Gulf Coast Tertiary until after the stratigraphic correlations have been made (Figs. 28-29).

Those who have worked with areas of platform facies, like northern Oklahoma, Kansas, and Nebraska, may find little that is familiar to them in the Gulf Coast Tertiary. Similarities between the Pennsylvanian of the Mid-Continent and the Gulf Coast Tertiary increase as one approaches the McAlester and the Anadarko geosynclines in Oklahoma, and the later Paleozoic of the western Appalachians (Storm, 1945). Kenneth E. Caster (1934, pp. 19-36) has discussed a systematic facies distribution in the late Devonian and early Mississippian of western Pennsylvania that is strikingly similar to the distribution of facies under regressive conditions in the Gulf Coast late Tertiary.

Another example of similar-facies distribution has been described from the Tertiary of Burma by L. Dudley Stamp (1927). Recent work in Burma (Tainsh, 1948) has tended to confirm in a very general way the facies changes illustrated by Stamp. The diagrammatic method used by Stamp to represent the facies changes seems to imply the transection of paleontological zones by precisely bounded stratigraphic units. This condition apparently does not exist.

There are many other areas of rapid, detrital, shallow-water, marine, and brackish sedimentation (paralic sedimentation, Tercier, 1939) in elongate depositional areas which should possess a high degree of similarity to the Gulf Coast Tertiary. Some of these are the Westphalian coal basin on the north flank of the

Variscan geosyncline, the Flysch and Molasse of the northern Alps, part of the Tertiary geosynclines of the East Indies. Some of these examples are in the general class of paralic sedimentation in foredeeps (Umbgrove, 1947), though these geosynclinal "foredeeps" are not necessarily related tectonically to the foredeeps of island-arc provinces.

The facies changes in the Tertiary of the Gulf Coast probably possess a high degree of similarity to a much more general class of sedimentary deposits, namely, the transgressive and regressive paralic deposits, whether in foredeeps, intermountain basins, the shoreward parts of epicontinental deposits, or the shoreward facies of broadly basinal areas of deposition. The Pennsylvanian cyclical sedimentation of Illinois and Ohio has been cited previously. Stamp has shown the transgressive-regressive conditions in the sedimentary cycles of the Paris basin. Miscorrelations, resulting from facies change in the Albian between England and Ireland, have been cited in several places in the literature. The Tertiary of the Maracaibo basin in Venezuela offers conspicuous examples of facies change. The Washita-Fredericksburg (Lower Cretaceous) furnishes an illustration in East Texas, as does also the Woodbine-Eagle Ford (Upper Cretaceous), the Paluxy (Lower Cretaceous), the Schuler-Cotton Valley (Jurassic), the Lower Paleozoic in the Marathon region, and so on until one has named probably more than half of the problem areas in stratigraphic geology.

Density of information in subsurface of Gulf Coast.—In some of the areas named, the rate of sedimentation was higher than in the Gulf Coast Upper Tertiary; in most, it was lower. In a few instances, the basin of deposition is narrower and the rate of facies change is higher; in most of the instances, it is lower. But in all of them are problems involving the interrelationship between the distribution of bio- and lithofacies under conditions of horizontal change that take place, in many instances, at a rate that is greater than can be controlled by available data.

The Gulf Coast Upper Tertiary appears to be exceptional in that the rate of facies change in a direction normal to the depositional axis is nicely balanced by the present density of information. If the rate of change were slower (as in the Eocene of the Gulf Coast) a large part of the story would be lost, either by erosion at the outcrop or by being too deeply buried to be reached by the drill. If, on the other hand, the rate of facies change were much greater, the general pattern would remain unknown for several years until the regional density of information was adequate to decipher the relationships which are so readily apparent to-day.

Epicontinental (foreland) areas and peripheral part of broad shallow basins.—The Pennsylvanian rocks of the mid-continental region of the United States from Nebraska to Texas furnish an example of a sedimentary province in which the facies and faunal patterns of distribution appear at first glance to have little in common with those in the Gulf Coast Tertiary. Similar sequences of thin limestone, separated by thicker bodies of shale, contain the same diagnostic sequences of fusulinids in areas as far apart as North Texas and Nebraska. The intervening

shales are, for the most part, barren of fusulinids, and the genetic relationships between guide species in one limestone to those in another are inferred. Obviously the distribution of the fusulinids in the vertical section is restricted by intermittent facies. Evolution must have gone on somewhere in order for the species to evolve. Furthermore, there is no reason to believe that the old species died out everywhere at the instant that the last lamina of fusulinid limestone was deposited. Here also, we appear to be dealing with partial zonation, and with little likelihood of discovering a total section of uniformly favorable facies in which the total zonation can be established. It appears that here, as in the Gulf Coast Tertiary, stratal correlation has been produced by a network of high-probability local and subregional comparisons using all available stratigraphic data, of which the fusulinids form one of the more important parts.

The Gulf Coast Tertiary shows a continuity of facies along strike that is similar to the widespread facies continuity seen in the mid-continental Pennsylvanian. In particular, the presence of diagnostic species of larger foraminifera in thin limestones and marls of the Gulf Coast Eocene, for hundreds of miles along strike, is suggestive of the distribution of fusulinids in Pennsylvanian limestones. One of the conspicuous differences between the Gulf Coast geosynclinal Tertiary and the mid-continent epicontinental Pennsylvanian lies in the width of the bands of similar facies paralleling the deposition axis of the basin. In areas of late-phase geosynclinal deposition, such as occur in the Pennsylvanian of the McAlester and Anadarko geosynclines, the band of equal facies might be as narrow as those in the Gulf Coast Tertiary. Analysis of facies patterns in the borderland between epicontinental and geosynclinal areas in the Pennsylvanian should be highly instructive in making a detailed comparison of the two types of sedimentary provinces.

NEED FOR ADDITIONAL DATA

In the foregoing discussion an attempt is made to contribute to the available facts in one segment of the field of sedimentology as it may be applied to interpretations of depositional environments. Attention has also been given to possible methods of using these data in stratigraphic correlation because, in order to have any meaning, interpretations of depositional environment must rest on a sound framework of stratigraphic correlation.

Paleontology—more specifically the micropaleontology of foraminifera—has been used as the example because it appears to be the most effective tool with which to investigate the environmental aspects of sedimentary facies in the Gulf Coast Upper Tertiary. But the investigation of Recent foraminifera was undertaken to learn something about the sediments as a whole, not merely the fossils. The recognizable fossils in a sedimentary rock form a small percentage of it by volume, but they are representatives of a hoard of organisms that lived above, on, and under, the surface of the mud. These organisms are only part of a biochemically interacting environment that is composed of water, solid inorganic particles, dead organic matter, and living organisms. No one can study the

seething mass of organisms in the single centimeter of scum that rests on the surface of the bottom mud without realizing that any division of a sedimentary rock into fossil and non-fossil is purest fiction. Work with Recent foraminifera will have missed its primary potential value unless it succeeds in pointing out the need for additional classes of data and ways in which we might go after them. It has already been suggested (p. 1951) that the distribution of faunas in Recent sediments can serve as a preliminary survey that would be useful in outlining an investigation of other sedimentary properties. It probably can serve also in expanding that frame-of-reference to include the sedimentary rocks and thereby help devise still other investigations of the changes which take place after deposition. The investigation of some of these properties, such as the shape and size-distribution of medium-grained particles, is already well under way and is available as collateral evidence in framing a further plan of action. Still other properties, such as those pertaining to clay-size particles, organic content, magnetic properties, and radioactivity, appear to offer new classes of useful data. When all of these have been brought further under control, we shall have brought additional large segments of the sedimentary column within our effective sphere of interpretation.

The need for additional information on sedimentary facies may be further emphasized by applying what little is known to the question of the Gulf Coast geosyncline.

GULF COAST GEOSYNCLINE?

The subject of geosynclines has recently been reviewed by Glaessner and Teichert (1947). They present a summary of the geosynclinal concept as it exists in the literature. The term apparently is used by most modern authors as signifying a mass of sedimentary rock of regional extent, which occurs in much greater thickness than beds of similar age in adjacent areas. Geosynclines are subdivided on the basis of the shape of the sedimentary mass, the tectonic framework, and location relative to the continental shield, the kind and amount of igneous activity, the degree of folding, and the stratigraphic architecture.

The Gulf Coast Tertiary has been classed as a geosyncline (Barton, Ritz, and Hickey, 1933; Kay, 1944), but this classification has been questioned, principally because of inadequate information about the character of the southeast limb of the mass. The stratigraphic distribution of sedimentary facies can be brought to bear on this question.

All eight of the major cyclical units in the Tertiary thicken toward the Gulf at two distinct rates of thickening. On the landward side of their development they thicken at a fairly constant rate in terms of feet per mile. In the down-dip area, the rate of thickening increases geometrically. The narrow zone between these two rates of thickening is called the flexure. This is shown diagrammatically in Figure 30.

It is notable that the sediments in the area of the flexures of all the cyclical units are either continental-shelf facies or continental shelf interbedded with

brackish facies. This observation agrees with the hypothesis that the continental shelf was a highly mobile constructional land form which migrated seaward or landward in response to subsidence and to the rate at which detrital sediment was brought into the province during the Tertiary. According to this hypothesis, if sedimentation exceeded subsidence the shelf migrated seaward under regressive

CENOZOIC FLEXURES

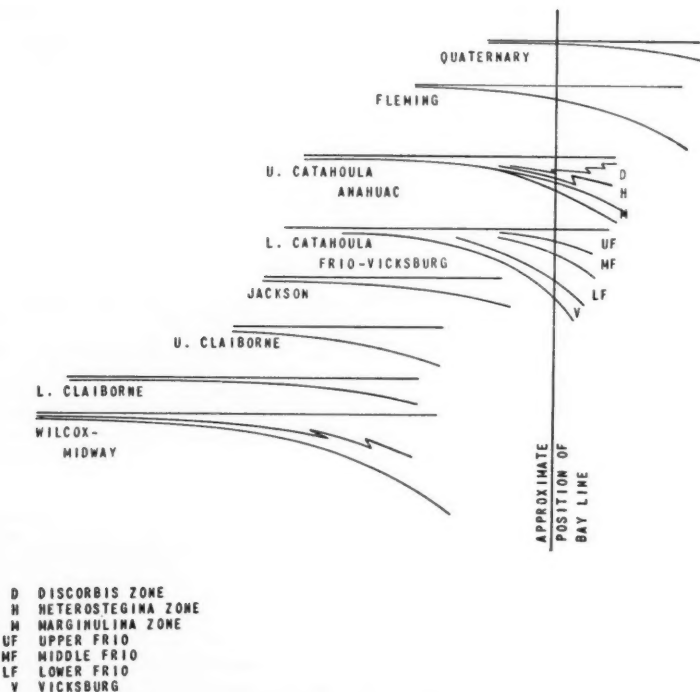


FIG. 30.—Diagrammatic representation of the major cyclical sedimentary units in Gulf Coast Tertiary showing position of their rapid thickening (flexure) relative to bay-line.

conditions of sedimentation. If, on the other hand, subsidence exceeded sedimentation the shelf migrated landward under transgressive conditions. There appears to be no other interpretation which agrees with the transgressive and regressive character of the cyclical units in the Gulf Coast Tertiary. Therefore, since sedimentary flexures must occur during times and in areas of rapid subsidence and rapid sedimentation, it can be shown that the sedimentary-tectonic

processes would be most apt to produce migration of the shelf toward the area of the flexure.

Each of these flexures occurs progressively farther seaward than the preceding one, and it is interesting to note that similar migration of flexures is a well known characteristic of certain linear geosynclines. What is much more to our purposes, a large part of the oil in the Gulf Coast occurs along these flexures. This may be due to the concentration of favorable structures along the zone between slow and rapid subsidence. But it probably is due to the combination of favorable facies and structures.

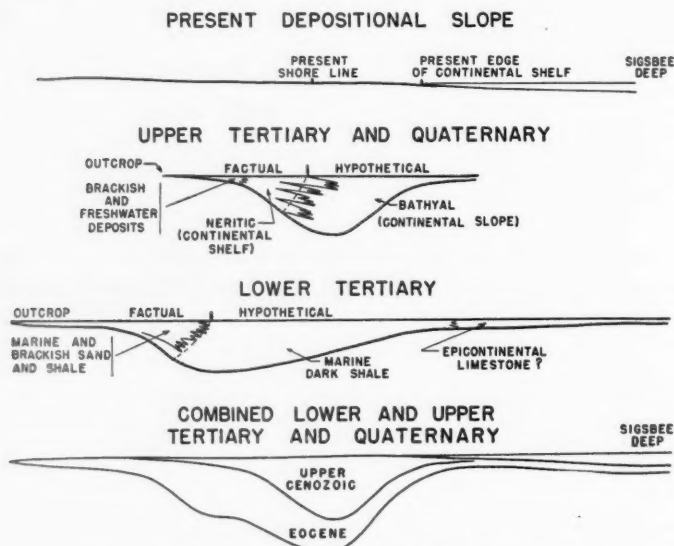


FIG. 31.—Hypothetical reconstruction of Gulf Coast geosyncline.

Since every one of the cyclical units from the Eocene to the Quaternary thickens gulfward at geometric rates, it can be shown that if the same rate of thickening continued there would be 100,000 feet of Tertiary beds at the coast and more than 100 miles of section in the vicinity of the present edge of the continental shelf. This, of course, is a geological absurdity. There must be some decrease in the rate of thickening or a reversal. The evidence in the Eocene suggests that the central part of the Gulf might have been epicontinental in character during that time. The evidence is the wide landward extent of the Eocene into the transverse embayments, the gentle depositional slopes, the absence of known continental-slope faunas (below the Jackson), and the character of the sediments on the southeast Mississippi platform which Bornhauser (1947) interprets as the northern edge of the Gulf of Mexico stable plate.

If the central Gulf were epicontinental during the Eocene, then shallow-water processes would tend to distribute the sediments widely, and the southeast rate of thinning toward a central "plate" would depend on the rate of subsidence plus rate of inflowing sediment. The central Gulf would fill up or deepen depending on the subsidence-sedimentation ratio. This sounds like conditions in other geosynclines with shallow-water seaward limits such as the Upper Devonian of western New York, Pennsylvania, West Virginia, and Ohio. A basinward rate of thickening comparable with that recorded for the Appalachian Devonian would give a curve for the Eocene element of the Gulf Coast geosyncline somewhat like that in the lower middle diagram of Figure 31.

Contrary to the Eocene, the evidence in the Upper Tertiary favors the hypothesis that the central Gulf was a deep hole, like it is to-day, though not necessarily in the same geographic location. The evidence for this hypothesis is the absence of the Upper Tertiary from the transverse embayments, the relatively steep depositional slopes, and the presence of continental-slope facies near the seaward limit of drilling of several Upper Tertiary units.

If there was a deep hole in the central Gulf during the Upper Tertiary, then the southeastern limb of the Gulf Coast geosyncline might be expected to be rather steep in the Upper Tertiary. This expectation seems reasonable because there would have been no shallow-water processes to distribute the sediment seaward. Considerable thicknesses of sediment may have accumulated on the upper continental slope but these sediments could have been incorporated either in the northwestern or in the southeastern limb of the geosyncline. The upper middle curve in Figure 31 is based on this hypothesis.

The bottom curve in Figure 31 is a combination of the two middle curves and gives a hypothetical cross section of the Gulf Coast geosyncline in the Cenozoic.

SUBSIDENCE UNDER SEDIMENTARY LOAD?

Glaessner and Teichert (1947), in a recent review of the literature on geosynclines, reached the conclusion that,

Concerning the actual mechanism of the formation of geosynclines, it would seem that the school of Gulf Coast geologists has produced such weighty arguments in favor of subsidence under load that the operation of this factor can no longer be doubted.

If the Gulf Coast is to be the proving ground for the theory of subsidence under load, it seems highly desirable to bring as much evidence as possible to bear on the question.

A large part of the evidence cited occurs in the area of the Mississippi delta. That evidence has been interpreted as showing that there has been subsidence as a result of the loading in the delta, and that in consequence of that loading there are isopachal maxima under the delta in the Quaternary and Pliocene-Miocene. It would require several pages to review the evidence presented by Russell and Fisk (1939), Russell (1940), and Fisk (1944). It is more to the point to present new evidence.

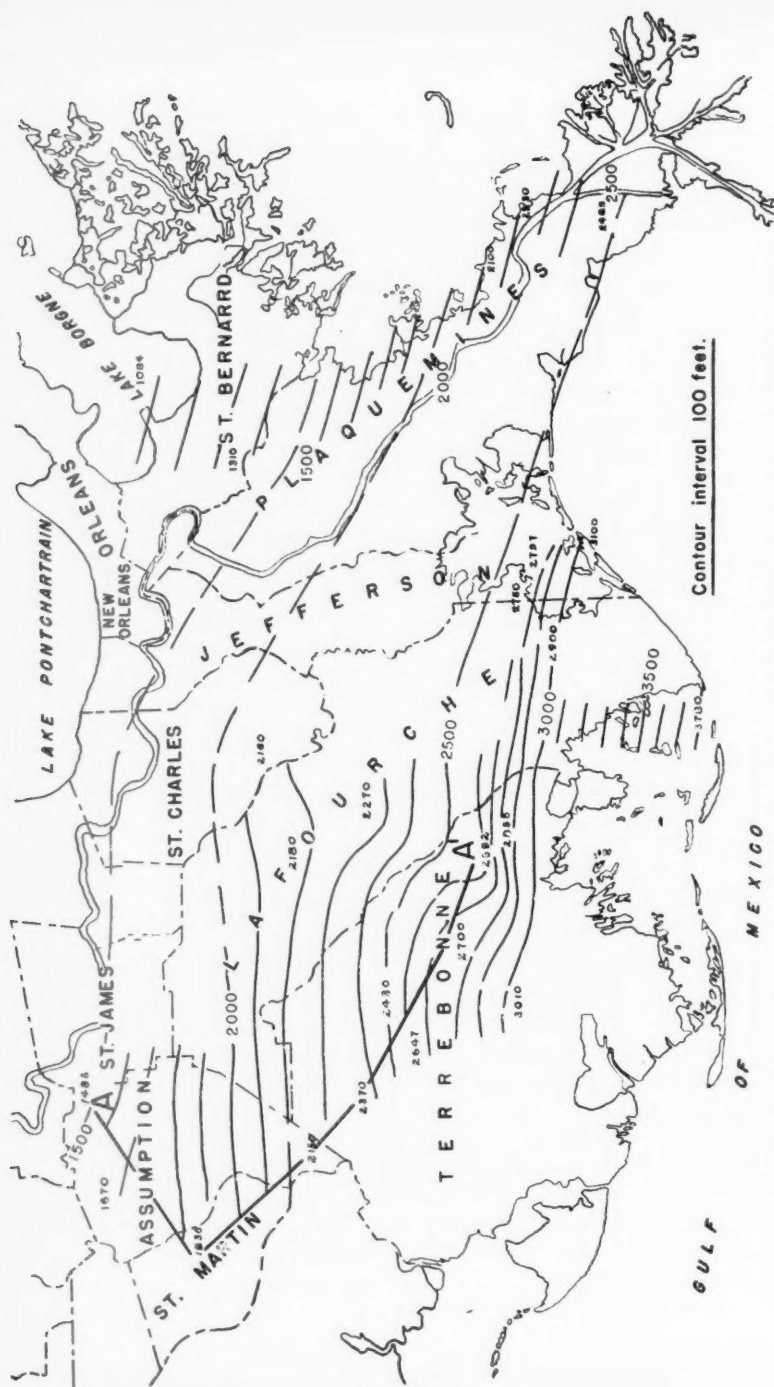


Fig. 32.—Structure contour map on base of the "Upper Marine beds" (Pleistocene) in area of Mississippi delta.

Figure 32 is a structure-contour map drawn on a datum near the base of the Pleistocene. According to this interpretation there is uninterrupted south dip across the delta, with a slight southwesterly component in the eastern part of the areas. Figure 33 is a cross section drawn from north to south approximately across the middle of the delta (AA', Fig. 32). The base of the marine Pleistocene ("Upper Marine beds") is used as the datum plane for this cross section and for the structure map.

The marine facies of the Pleistocene is more than 1,000 feet thick under the central part of the delta and it rests on continental beds which are several thousand feet thick. A diagrammatic range chart at the right side of Figure 33 shows the nature of the faunal distribution in the marine Pleistocene, and in the underlying brackish beds which contain only *Rotalia* and *Elphidium*. Seven hundred feet below the base of the marine Pleistocene is a bed which contains a few per cent of fresh volcanic glass. In two wells there appear to be two glass-bearing beds close together, but there is no other notable concentration of glass for more than 1,000 feet above or below these two beds.

In the writer's opinion, the published isopach maps of Fisk (1944, pp. 68-70), which show maxima under the delta in the Quaternary and the Pliocene-Miocene, are based on facies criteria which transgress planes of stratification; therefore, they are isopachs of equivalent facies, not equivalent stratigraphic intervals.

In the writer's opinion, also, the data on the base of the marine Pleistocene and the volcanic glass eliminate the probability of major isopachal thick areas in the Quaternary under the Mississippi delta. And this, in turn, seems to eliminate the delta area as a major special category in considering subsidence under load in the Gulf Coast geosyncline.

There are three general cases of basinward thickening that add to the analysis of the stratigraphic architecture of the province and at the same time bear on the question of subsidence under sedimentary load.

The first of these three cases may be represented by a hypothetical cross section showing basinward thickening of a single stratigraphic unit (Fig. 34-b) deposited during a time of constant inflow of sediment into the subprovince. In this case, there is only one principal variable in the distribution of the sediments, namely, subsidence. The numerous differentiations in the sediment, such as facies distribution, are the result of processes which operate on the depositional slope. The depositional slope is the product of rate of subsidence and rate of sedimentation. The rate of sediment flowing into the subprovince is constant by definition, which leaves subsidence as the only principal variable in this instance. Thickness also is the result of contemporaneous subsidence and sedimentation. Nothing can be deduced as to the cause of subsidence, in this instance, because all the other variables are dependent.

A dip section of a cyclical sedimentary unit may be considered as the second case (Fig. 34-c). In this case, there are different volumes of sediment entering the basin at different times during the deposition of the unit. This difference in rate

La Pice West Lake Verret Shell Oil Co.
Field H.W. Ellis
St James St. Martin Ph. Assumption Ph.
Gibson Field Terrebonne Ph.
South Houma Field Terrebonne Ph.

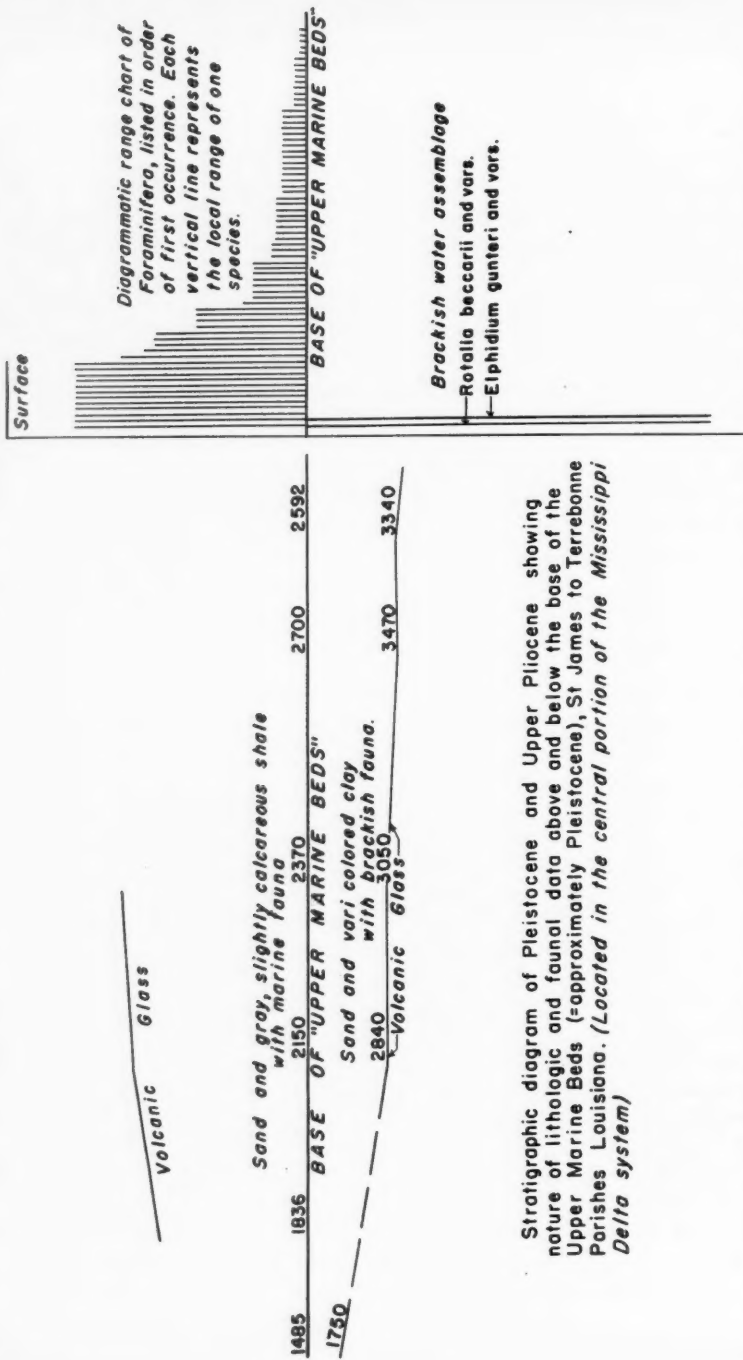


FIG. 33.—Stratigraphic diagram of Pleistocene and upper Pliocene, St. James to Terrebonne parishes, Louisiana, in central part of Mississippi delta. Diagrammatic range chart in Lirette field indicates nature of facies in "Upper Marine b-ds" and sharpness of marine transgression at base of "Upper Marine beds."

of sedimentation is shown by the lithologic differences at different levels in the unit (Figs. 3 and 23). There are also correspondingly different rates of subsidence as shown by the relatively rapid subsidence during the deposition of great thicknesses of strata, and slow subsidence during slow clear-water deposition of the limestone and marl. The rate of subsidence and rate of sediment entering the sub-province appear to correspond so closely that causal relationship is indicated. Did the sedimentary load cause the subsidence? Did the subsidence provide a place for the sediment? Or was there equivalent tectonic activity in the area of source and in the basin of deposition, thereby producing a calibration of the

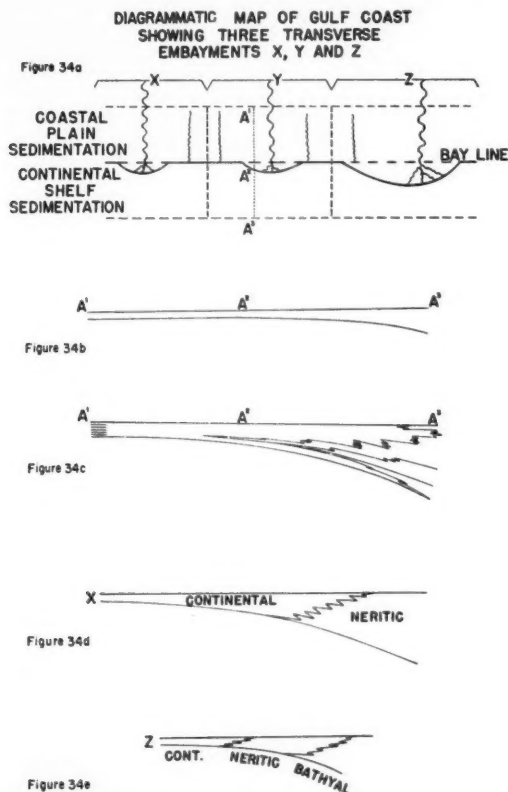


FIG. 34.—Gulfward thickening of cyclical sedimentary unit. 34a.—Diagrammatic bay-line base map of Texas and Louisiana Gulf Coast with three major embayments: X, Rio Grande; Y, Colorado-Brazos (central); and Z, Mississippi. 34b.—Cross section of single stratigraphic unit along line A^1 - A^2 - A^3 deposited during constant rate of influx of sediment into embayment Y. 34c.—Sedimentary cyclical unit deposited during different rates of influx of sediment into embayment Y. 34d-e.—Two cross sections of same cyclical unit located in embayments X and Z showing narrow shelf for thin section and wide shelf for thick section.

volume of sediment and the amount of subsidence? The answer does not appear to be in the stratigraphy.

In the third case (Figs. 34-d and 34-e), there are different rates of subsidence and correspondingly different rates of sediment entering two widely separated subprovinces (x and z) during the same stratigraphic interval. Figure 34-a is a diagrammatic map of the Gulf Coast area, x being the Rio Grande syncline, y the central syncline, and z the Mississippi River syncline. The apparently calibrated rates of subsidence and sedimentation in the Rio Grande (Fig. 34-d) and in the Mississippi River (Fig. 34-e) synclines coupled with the difference between the rates in the two areas may seem like evidence of subsidence in response to load. However, the Rio Grande syncline, which is the area where the thick sediments occur, is nearer the mountains; hence, it may be the site of greater tectonic activity and correspondingly greater sedimentation. In this instance as in the other two, the stratigraphic evidence does not appear to be conclusive.

COMPARISON OF GULF COAST WITH LATE CENOZOIC-RECENT COUPLETS IN OTHER REGIONS EXTENSIVELY DRILLED FOR OIL

The Gulf Coast is one of the few, extensively drilled regions where the producing series are nearly continuous geologically with modern environments of deposition. As part of the geologic past, the Gulf Coast Tertiary can be investigated by geologic techniques that were developed in the more classical Mesozoic, Paleozoic, and pre-Cambrian. As a part of the late Cenozoic-Recent community, it shares the advantage of being in a position where these methods can be tested against data and relationships in modern environments of deposition. Since the greatest single coordinating factor of sedimentology appears to be environment of deposition, the potentialities of this gateway position are obvious.

There is another region in the United States in which the late Cenozoic approximates geological continuity with the Recent and in which there are enough wells to supply adequate material for comparative study with the Recent. That is the Pacific Coast (A, Fig. 35). One of the most striking comparisons exists between the Los Angeles basin and the submerged depressions off the coast of southern California and northern Mexico.

It has been suggested that the Pliocene and Pleistocene of the Los Angeles basin were deposited in a basin which subsided only a little after the Pliocene deposition began. Such an environment doubtless would produce depositional patterns that would contrast in some significant aspects with those that occur in the Gulf of Mexico.

The Maracaibo basin in Venezuela (B, Fig. 35) is another area in which late Tertiary beds occur in near-continuity with the Recent and in which there is a great abundance of material available from wells. The late Tertiary is predominantly continental and the tectonic aspects of the sedimentary history do not appear to be so distinctly recorded as they are on the Gulf Coast.

A few other basins that are geologically continuous with great modern areas



FIG. 35.—Depositional provinces in Australasian and American intercontinental regions of deposition.

of sedimentation are the site of active exploration for oil. Among these is the Burma trough (C, Fig. 35) which has been mentioned previously. The patterns of distribution in the late Tertiary of Burma present points of similarity as well as difference to the late Tertiary of the Gulf Coast.

A striking comparison has been cited by J. Tercier (1939) between the Gulf of Mexico-Bahama-Caribbean region on the one hand and the East Indies on the other (Fig. 35). Both regions are composed of basins, platforms, and archipelagoes that lie between two continents. Both have interbedded brackish and shallow marine (paralic) sediments in the northwestern part of the region in the Recent and thick paralic geosynclines in the Tertiary. In the southeastern part of both regions, there are platforms and island-bordering shelves that are covered with carbonate deposits in the Recent. The late Tertiary and Quaternary of these southeastern areas is made up, for the most part of relatively thin limestone deposits. Both regions contain island arcs and submarine troughs that are unfilled with sediment. The similarities of sedimentation and structure are so numerous and so striking that it seems reasonable to suggest that the stratigraphic architecture of the Gulf Coast and Sunda geosynclines may possess many points of similarity.

These few examples probably do not contain all the paralic types of sediments and sedimentary rock that produce oil. But they do contain enough to serve as gateways through which the needs of the geology can be expressed in terms of multiple investigations of Recent sediments, and through which in return the results of these investigations can be made available to the geology of older rocks.

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COMMERCIAL OIL IN CAMBRIAN BEDS, LOST SOLDIER FIELD, CARBON AND SWEETWATER COUNTIES, WYOMING¹

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ABSTRACT

The possibility of finding oil in the basal sands of the Cambrian of Wyoming has long been a matter of speculation. The Cambrian, where well developed, consists of marine shales and limestones in the upper part and a rather thick series of coarse-grained sandstones near the base.

Several comparatively shallow tests had been drilled to test the Cambrian on large, well closed structures prior to 1930 but the results were either negative or the reported showings were in doubt.

A deep test to granite on the South Oregon Basin field in 1945 found definite indications of oil saturation in basal sands of the Cambrian but due to mechanical difficulties no free oil was recovered from the well.

A test to granite in the Lost Soldier field, Sweetwater County, Wyoming, in 1948 resulted in the first commercial well in the Cambrian in the Rocky Mountain region. During the year two additional wells were drilled through the Cambrian in the Lost Soldier field. One of these was completed as a commercial flowing well but the other found the formation too dense to produce. In the same year a producing well was completed in the Cambrian on the adjoining Wertz dome.

The Cambrian, which is represented by the Deadwood formation in this area, is ordinarily hard and quartzitic but where oil-bearing it is softer and more friable. The total thickness of the Cambrian is as much as 700 feet but the oil-bearing zone is near the base, almost in contact with the basement complex.

It is the writer's belief that the oil produced at Lost Soldier and Wertz from the Cambrian is not indigenous to that formation but has migrated laterally from overlying oil-bearing reservoirs after accumulation in the structure.

The writer believes that a well could be drilled at the crest of the Lost Soldier dome, which would yield oil from the basement complex if that formation were penetrated above the oil-water contact in the Tensleep sand.

INTRODUCTION

It is the purpose of this paper to describe the occurrence of oil in the Cambrian in the Lost Soldier and Wertz fields in south-central Wyoming. This is the first instance of actual commercial production from beds of definite Cambrian age in the Rocky Mountain region.

Oil was discovered in the Cambrian Deadwood sand in the Lost Soldier field in the Drayton well No. 2, completed on June 26, 1948, at 5,965-6,130 feet, initially producing 720 barrels per day, flowing by gas lift. A second well (No. 111A) was completed in December, 1948, flowing 601 barrels per day, natural, from the same zone. Well No. 13, Hughes A, in the same field was drilled through the Cambrian and 176 feet into the pre-Cambrian, but in this well all of the Cambrian and also the pre-Cambrian contained oil-stain in streaks but was dense and impermeable and yielded no oil on drill-stem test. The well was plugged back to produce from the Madison limestone of Mississippian age which lies on the Cambrian.

Well No. 26 on the Wertz dome was drilled through the Cambrian in September, 1948, and completed as a small well making about 200 barrels of oil per day

¹ Read before the Association at St. Louis, March 16, 1949. Manuscript received, June 13, 1949.

² Consulting geologist. The writer is indebted to Robert L. Sielaff, district geologist for Sinclair-Wyoming Oil Company for helpful suggestions and the current well data. The Sinclair Wyoming Oil Company is the only operator in the Lost Soldier and Wertz fields.

with much water. It is somewhat doubtful whether this well will be a commercial producer for very long, but it has proved the presence of oil in the Cambrian at Wertz dome, which is a separate and distinct structure from Lost Soldier.

A well completed in September, 1923, on Pine Mountain dome, Natrona County, Wyoming, reported light oil in the top of the Deadwood sand, which is the basal member of the Cambrian. Water was encountered underlying the oil and, although the report caused considerable excitement, it was not generally accepted.

The Prairie Oil and Gas Company drilled a test well in 1928 on Little Sheep Mountain dome, Big Horn County, Wyoming, which had as its principal objective the testing of the Deadwood sand of the Cambrian. This well was a dry hole, but was the first well drilled in Wyoming solely as a Cambrian test.

In November, 1945, the Kirk Oil Company completed a well east of the crest of South Oregon Basin dome, Park County, Wyoming, to test all formations below the Madison limestone. The Deadwood sand from 5,930 to 6,348 feet showed indications of oil from drill cuttings and a core from 6,348 to 6,354 feet consisted of soft friable sand, fully saturated with straw-colored oil. The well was drilled to granite at 6,424 feet and casing cemented to bottom. When tested through perforations, the well made only water from the Deadwood formation.

This paper is limited to the discussion of the occurrence of oil in the Cambrian, but brief description of the Lost Soldier and Wertz dome structures is necessary to provide the proper background.

STRATIGRAPHY

The surface beds at the crests of both Lost Soldier and Wertz domes are Steele shale of Upper Cretaceous age, covered in part by terraces of Pleistocene gravel. According to local usage the base of the Steele shale is a sandy zone which has been named the G.P. sand and the part of the Steele shale below the G.P. sand down to the top of the Frontier sandstone is Niobrara in age. The G.P. sand forms a low rim around the surface crest of the Lost Soldier dome, but at Wertz this sand is approximately 1,000 feet below the surface.

The Mesaverde sandstone group forms an outer and higher rim which almost surrounds the Lost Soldier field except on the side toward Wertz dome. This Mesaverde rim also flanks Wertz dome on the northeast and south.

The Frontier formation is about 550 feet thick and consists of sandstones separated by sandy shales. Essentially there is a thick upper sand and a much thinner basal sand with shale between, but the sand zones thicken and thin laterally and contain many shale breaks. At the crest of Lost Soldier dome the top of the Frontier sand is 190 feet below the surface, and at Wertz it is about 2,300 feet below the surface.

The generalized stratigraphic section from the top of the Frontier zone to the basement granite in the Lost Soldier district is as follows.

	<i>Thickness in Feet</i>
CRETACEOUS	
Frontier formation.....	550
Benton shales including Muddy sand.....	750
Dakota group containing the Dakota and Lakota sands separated by dark shale.....	220
JURASSIC	
Morrison formation. Variegated shale with sandstones here and there.....	340
Sundance formation	
Marine shale.....	30
Sundance sand.....	350
Jelm formation. Sand and redbeds.....	350
TRIASSIC	
Alcova limestone.....	10
Triassic redbeds.....	850
PERMIAN	
Embar, limestone, anhydrite, and redbeds.....	300
PENNSYLVANIAN	
Tensleep sand.....	400
Amsden dolomite.....	120
Amsden red shale.....	100
Amsden-Darwin sand.....	100
MISSISSIPPIAN	
Madison limestone.....	450
CAMBRIAN	
Deadwood formation.....	710
PRE-CAMBRIAN	
Granite and schist	
Total.....	5,530

In the Wertz field the Frontier sands and the Sundance sand contained a little gas. The Dakota and Lakota sands contained much gas. The Tensleep sand, the Darwin sand, and the Madisonli mestone are important oil zones. The Cambrian, now producing from one well, does not appear to contain much oil.

The Darwin sand where tested seems to be well sorted and porous and may become an important reservoir.

In the Lost Soldier field practically every sandstone with any kind of porosity, also the Madison limestone, and some crevices, or similar types of porosity in otherwise impervious beds, from the grass roots down and including the basement rocks, contain oil in varying amounts. The principal oil-producing zones are the First Frontier (First Wall Creek), Dakota, Lakota, Sundance, Tensleep, Madison, and a 200-foot zone in the basal Cambrian.

STRUCTURE

Lost Soldier and Wertz are closely related domes, located 2 miles apart and separated by a deep syncline. This relation is shown on the structure-contour map (Fig. 1).

Wertz dome is the westernmost high on an anticline about 25 miles long with an east-west trend. Other local highs or domes on the same anticline are Bailey, Mahoney, East Mahoney, and Ferris domes. The trend of the elongate axis of Wertz dome is N. 45° W.

Wertz dome is an inside fold. It has practically no drainage outside the limit

of closure of the dome itself. Lost Soldier dome is west and southwest and Bunker Hill dome is close beside it on the northeast. It has steep dips on the northeast and flatter dips (20°) on the southwest side. The closure of Wertz dome is in excess of 1,000 feet, being least on the southeast end where a saddle separates it from Bailey dome.

The Lost Soldier field is on the extreme crest of a very large egg-shaped dome southwest of, and *en échelon* with the Wertz dome. Structurally it rises as a single, ovate peak from the floor of a deep basin. It is definitely a basinward fold with very large drainage area. The closure is in excess of 4,000 feet, being least on the east side where it lies closest to Wertz dome. On the west, south, and northwest the flanking formations plunge many thousand feet into the deep Red Desert basin. The trend of the long axis of the Lost Soldier dome is N. 20° W. The surface beds on all sides of the crest dip outward at 35° - 45° .

Both Lost Soldier and Wertz can be readily mapped from surface rocks, but the surface structure does not conform with the subsurface structure because of the attenuation of beds on the northeast flank of each dome, and to numerous unconformities on the crest of Lost Soldier dome.

The Lost Soldier dome is complexly faulted as would be expected on such a tightly folded structure. On or around the crest there are normal faults of the radial or dip type. On the steeply dipping northeast flank the beds are not only thinned by stretching, but are probably actually torn apart. It is also probable that a deep-seated fault in the basement in the syncline along the east side may be slightly overthrust eastward. It is believed that the intense faulting provides channels along which oil migrates from one reservoir to another.

The Wertz dome appears to be without faults.

DEVELOPMENT

Oil was discovered in the First Wall Creek sand in the Lost Soldier field in 1916 at a depth of 265 feet. The shallowest depth to the First Wall Creek sand in any well was 190 feet. This sand produced from about 160 acres and some of the wells flowed as much as 500 barrels per day, initial. In the producing area the first sand was 200 feet or more thick and was complexly faulted. Other sands in the Frontier group also contained oil, but these sands were erratic. Some wells produced for short periods from the shale above the First Frontier as shallow as 40 feet from the surface and from other streaks below the Frontier and above the Dakota at various depths, particularly in the Mowry siliceous shales of the Benton group.

The discovery well in the Dakota sand was drilled in 1919, and in the Lakota sand during the next year. This group of sands probably has produced more oil than any other zone above the Tensleep. The two sands are each about 60 feet thick and separated by 50-100 feet of shale, but in some parts of the field one or both sands may be missing. The productive area in the Dakota-Lakota covered 460 acres. The Sundance sand is 300 feet thick and where productive it lies at

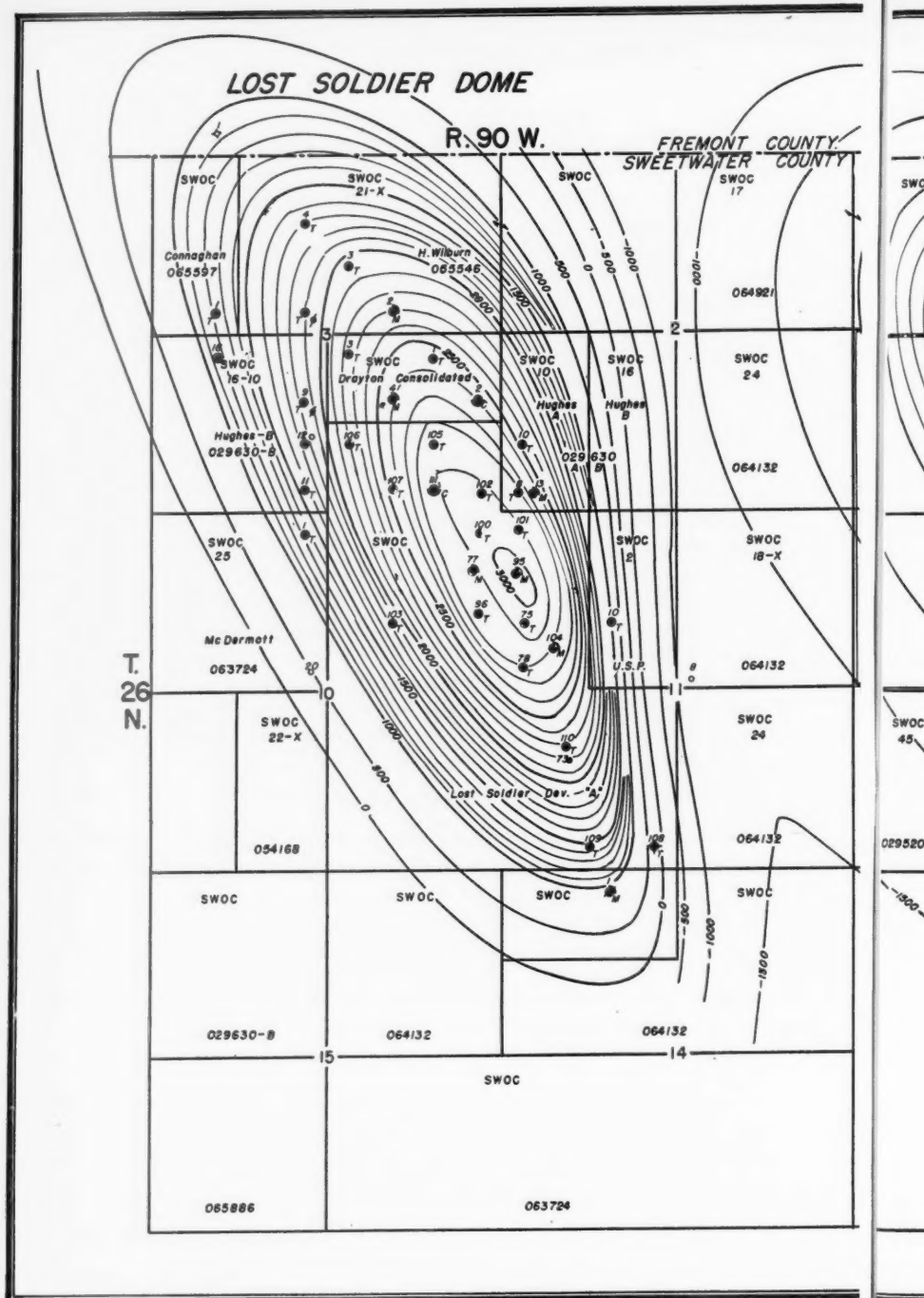


FIG. 1 (West half)

an average depth of 1,700-2,000 feet. This zone initially yielded very large flowing wells and has produced almost as much oil as the Dakota and Lakota. The productive area covered about 160 acres.

The zones from Frontier to Sundance inclusive have produced about 22 million barrels of oil and many of the wells are still producing.

The first Tensleep sand well (No. 75) was completed in 1930 at a depth of 4,000 feet. The Tensleep sand is approximately 400 feet thick and though it is rather fine-grained, dense, and very hard, it is productive throughout. The productive area covers about 1,000 acres and the height of oil column is approximately 2,400 feet (from 3,000 feet elevation to 600 feet elevation).

No wells were drilled in the Lost Soldier field below the Tensleep zone until 1948. In January, well No. 77 was completed as the discovery well in the Darwin sand and Madison limestone. The Darwin sand, though saturated, has not been found to be very porous and no wells have been completed in it to date. At the present time there are six wells producing from the Madison limestone. Most of these are old wells deepened from the Tensleep. The initial yields of the Madison wells varied from a maximum of 1,180 barrels per day to 600 barrels per day.

The Darwin sand, about 100 feet thick, is the basal member of the Amsden formation and rests directly on the Madison limestone. It is separated from the Tensleep in ascending order by about 100 feet of red shale and 120 feet of dolomite and sandy dolomite. The sand is commonly coarse-grained but contains much fine material and calcareous cement and is not very porous or permeable. It is saturated in many parts of Wyoming, wherever the Madison is oil-bearing, but the sand itself rarely produces commercially.

The Madison limestone is 300 feet thick at Lost Soldier and 450 feet thick at Wertz. It contains oil throughout but there is much dense, non-porous material and the best porosity is in the basal 200 feet.

The Madison rests directly on the Cambrian which in turn lies on a basement complex of pre-Cambrian schist and granite.

The Cambrian is about 700 feet thick in the Lost Soldier and Wertz fields and consists almost entirely of arkosic sandstone and quartzite. The formation contains glauconite throughout and the upper few hundred feet seem to include thin shale partings. The sand in general is very hard but where oil-bearing it may be soft and friable. Wherever porosity was encountered it contained oil stain. The porous productive sand is near the base and about 200 feet thick.

In the discovery well (Drayton No. 2) about 130 feet of pre-Cambrian schists and granites were drilled. The formation contained oil in crevices and some oil was recovered on drill-stem test.

Gas was discovered on Wertz dome in 1919 in the Dakota sand. The discovery well was spectacular mainly because it repeatedly snapped off casing and connections and blew wild. It made considerable distillate with the gas and the initial pressure was probably considerably above normal. The Wertz gas field was exceptionally profitable.

The Lakota sand also contained gas and a few wells made some gas from the Frontier sands and from the Sundance. A small amount of oil was produced from the Sundance after the gas was largely depleted.

The discovery well in the Tensleep was completed in the summer of 1939. The first wells were very large producers and were rated as capable of producing 6,000-7,500 barrels per day. The productive area of 640 acres has been developed with 24 wells, some of which were deepened to the Darwin, Madison, and Cambrian in 1948.

Bottom-hole pressures in the Tensleep at Wertz have been maintained by gas injection and the production holds up very well. The field has produced more than 16 million barrels of oil from the Tensleep to date. During 1948 six former Tensleep wells, two of which had ceased producing, were deepened. Well No. 32 at the south end of the field, which produced some oil and water from the Tensleep, contained water in all lower zones and has been abandoned. One well (No. 26) has been completed to produce from the Cambrian. The productive zone is in the lower part of the formation as at Lost Soldier. Two wells were completed to produce from the Madison, one well is producing from the Darwin sand, and another well is a dual completion in the Darwin and Madison. All are good wells with initials of 600-800 barrels per day except the dry hole (well No. 32) and the Cambrian well which is a 200-barrel well with much water.

ORIGIN OF CAMBRIAN OIL IN LOST SOLDIER AND WERTZ DOMES

The writer believes that the oil being produced from the Cambrian formation in the Lost Soldier and Wertz fields is not indigenous to the formation but has migrated into the Cambrian from the overlying oil-filled reservoirs. This migration has probably all occurred after accumulation in the structure and is therefore horizontal migration across the bedding rather than downward.

During his years of experience in the Rocky Mountain region the writer has evolved theories on the origin and accumulation of oil in sharply folded anticlinal structures of the region. Only those theories pertaining to the problem at hand are here mentioned.

Theory 1.—The amount of oil or gas that can accumulate in a structure is directly proportional to the drainage area contributory to it.

a. A structure with an enormously large drainage area like Lost Soldier should therefore contain much more oil or gas than one like Wertz with little or no drainage area.

b. If a structure contains oil and gas and has no present drainage area, at some former time it may have had access to drainage, at which time the accumulation took place.

Theory 2.—The amount of accumulation of oil or gas that a structure can hold or retain is directly proportional to the amount of closure within certain limits.

a. In areas of rapid circulation of formation water the amount and type of

WERTZ DOMES COUNTIES - WYO

WERTZ DOME

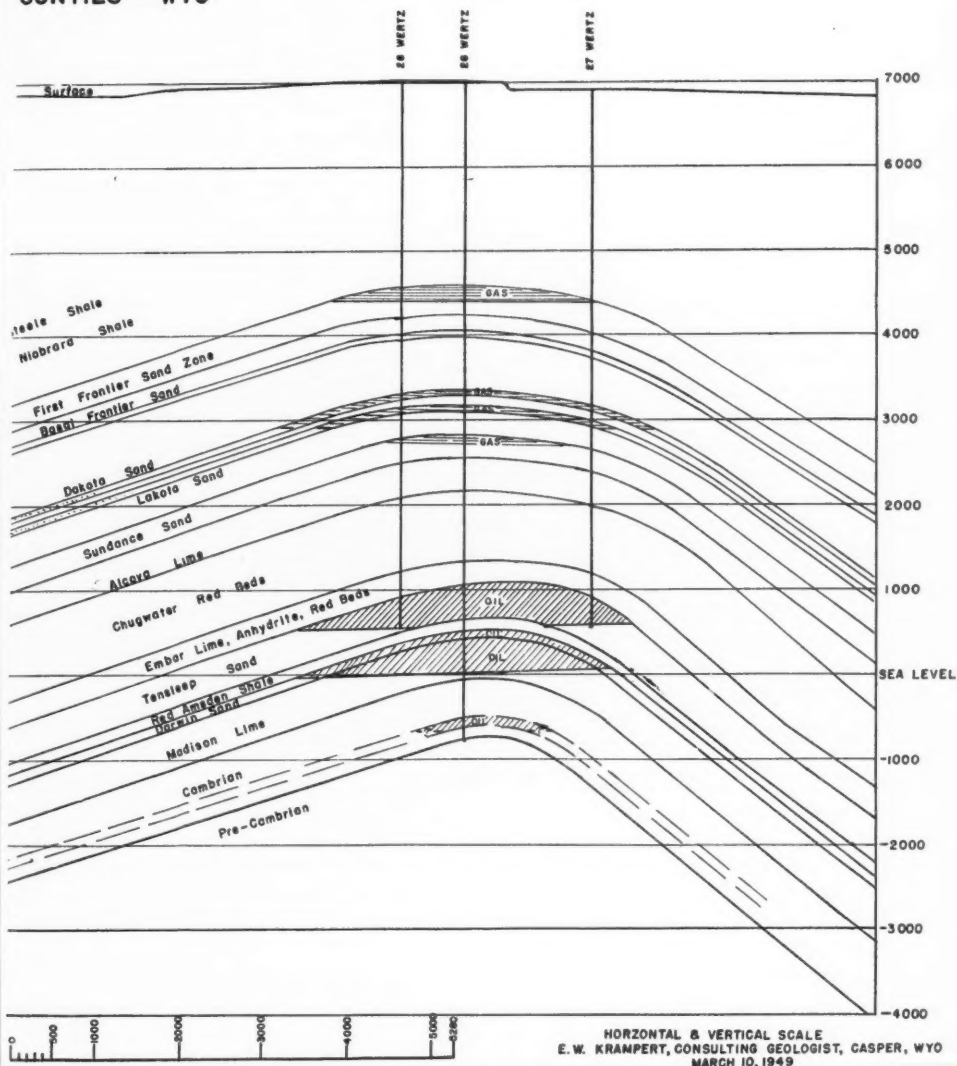


FIG. 2 (East half)

closure is most important. Such areas in turn correspond with areas where the reservoirs are thick and pervious. Structures near mountain uplifts where all reservoir rocks are exposed to water intake at the surface seem to require more closure than structures out in the basins and removed from areas of reservoir outcrop.

b. The immense amount of closure of structures like Lost Soldier is probably in excess of the amount needed to hold an equal amount of oil or gas.

c. Wertz dome, with 1,000 feet of closure, has enough closure to hold more oil and gas than it actually contains.

Theory 3.—The water-oil contact in any closely related group of reservoirs in sharply folded structures is at or nearly at a common level.

a. This theory has been tested in so many fields in the Rocky Mountain region that it is almost axiomatic. Exceptions, nevertheless, may occur and Wertz dome seems to be an outstanding example.

b. The Dakota, Lakota, and Sundance sands are closely related reservoirs and in Lost Soldier as well as in Wertz the water-oil contact is at a common level.

c. The formations from Tensleep to basement constitute closely related reservoirs and in the Lost Soldier field the water-oil contact appears to be at a common level, but this is not entirely proved. In the Wertz field, on the other hand, the Madison water-oil contact is 600 feet lower and the Cambrian water-oil contact is 1,200 feet lower than the Tensleep water-oil contact.

According to the foregoing theories, Lost Soldier should be a great oil field, and it really is. As previously stated, every streak of porosity from the grass roots down to and including basement granite contains oil.

This field, with a maximum of 1,000 productive acres will probably produce from a third to half as much oil as the famous Salt Creek field, which contains more than 30,000 productive acres, or the spectacular Rangely field with its 25,000 productive acres. It is surprising that it does not contain even more oil.

It is true that Wertz dome is a closed structure and is therefore capable of holding any oil or gas which may migrate into it, but the structure is so located that it has very little drainage area, whence, therefore, could oil or gas in any great amount come to be trapped in it? This particularly applies to the group of reservoirs from Tensleep to basement, which apparently are not interbedded with any beds that look as if they could be a source of oil. Compared with Lost Soldier, Wertz is probably a midget field. Nevertheless, Wertz has repeatedly demonstrated its ability to yield individual wells which surpass individual wells in Lost Soldier.

Bunker Hill, which adjoins Wertz on the northeast contains a little gas in stray sands but apparently contains no large accumulations of gas or oil.

Wertz is an outstanding exception to the writer's theory that the oil-water contact in closely related reservoirs in a structure should be at a common level.

All of the oil-water contacts in Wertz dome are definitely tilted in addition to being at different levels. Oil extends down farther in each zone at the north and west sides than on the south and east sides.

All the oil in the Tensleep, Darwin, Madison, Cambrian, and pre-Cambrian in Lost Soldier and Wertz fields is nearly the same in type. Wertz gravities may be a degree or so higher than Lost Soldier on the average. This suggests a common source for all the oil, but admittedly does not prove it.

The water-oil contact in the Tensleep is at 650 feet elevation at the south end of the Wertz field but may be a little lower at the northwest end. Incidentally, this is almost exactly the same as the water-oil contact elevation in the Tensleep at Lost Soldier. The water line in the Madison in the Wertz field is nearly at sea-level and the Cambrian oil is at 600 feet below sea-level.

The writer believes that the accumulation of oil and gas in the Wertz field must be ascribed in part to slight difference in age of folding between Wertz and Lost Soldier domes. Both structures had an early inception, but Wertz must have been folded up sufficiently to receive an accumulation of oil before the Lost Soldier upwarp started.

Later, as Lost Soldier started its growth it was raised much higher and faster and since its drainage was not intercepted the accumulation has extended over a much longer period. Probably by the time the Sundance, Dakota, and Frontier beds were laid down the Lost Soldier upwarp had risen considerably and all that Wertz received in the way of accumulation in these zones was a little gas.

It is probable that the accumulation of oil in the Wertz dome is due to several causes. All the seven local domes on the Lost Soldier anticline including Lost Soldier, Wertz, Bailey, Mahoney, West Ferris, Middle Ferris, and East Ferris probably receive their major drainage from the deep Red Desert basin on the west. Circulating waters with a movement in an easterly direction carry oil and gas originating in this deep basin eastward and Lost Soldier being first in line receives the most of it. Because of its huge closure it is able to retain much of it. The Wertz dome, second in line, also receives accumulation. The other domes, at the east, now contain less and less accumulation in proportion to their distance from the deep basin on the west.

It has been thought that the Tensleep sand was the principal carrier bed for the oil in the Paleozoic formations. It now appears that the Madison limestone may be even more effective as a carrier bed than the Tensleep.

The tilting of the water-oil contact in each reservoir and the difference in level of the water lines in the Tensleep, Madison, and Cambrian of the Wertz field may be due to a slight, comparative subsidence of the general region along with some northward tilting.

There is also some evidence of northward tilting in the Lost Soldier field, since there is considerable thickening of beds southward across the structure.

CONCLUSION

The theory that the Cambrian oil in Lost Soldier is not indigenous to the formation but has migrated through faults and crevices from overlying oil-filled reservoirs to its present position in porous sand almost immediately above basement rocks seems easily susceptible of proof.

The occurrence of oil in the same Cambrian reservoir at Wertz calls for complex theories of readjustment of structure, and modifications of the drainage theory which leave the validity of the writer's arguments very much in doubt; nevertheless, he feels that his theory of migration from overlying reservoirs is correct. If it were not so the oil would of necessity have originated in underlying beds, which in this instance are metamorphosed schist and basement granite.

ZONES OF PIERRE FORMATION OF COLORADO¹

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ABSTRACT

The stratigraphy of the Pierre shale, basal formation of the Upper Cretaceous Montana group in Colorado, is discussed in detail. Measured sections along the Front Range are described, and correlations of these sections with others in central and western Colorado are presented by means of three-dimensional diagrams. On the basis of lithologic and faunal characteristics the Pierre of northeastern Colorado is subdivided into four zones, from the base upward: the Sharon Springs shale zone, the Rusty zone, the Hygiene zone, and the Transition zone. Five units are locally recognized in the Hygiene zone, and three of these are present in much of Colorado. The Pierre zones are traced throughout eastern and central Colorado, and tentative correlations are suggested with the Mancos and Mesaverde formations of western Colorado.

The problem of the origin of the Hygiene sandstones is discussed. Regional lithologic studies indicate the possibility of a local origin of this sandstone tongue.

INTRODUCTION

Because of the great thickness and general homogeneity of the Upper Cretaceous Pierre shale of Colorado, it has long seemed necessary to subdivide this formation into smaller recognizable units. Several such subdivisions have been proposed but most have been applied to local areas only, with little attempt at any regional correlation. The purpose of this paper is to show, by means of detailed measured sections and fossil collections, a workable division of the Pierre formation on the basis of faunal and lithologic zones, to apply these zones to eastern and central Colorado, and to propose general correlations with equivalents in the western Colorado Mancos and Mesaverde formations.

The Pierre shale crops out in a large area of eastern Colorado and ranges in thickness from less than 1,000 feet in southern Colorado near Trinidad to approximately 8,000 feet in the northern foothills of the Front Range. In most of its extent, it is conformably overlain and underlain respectively by the Fox Hills sandstone and the Niobrara formation. Almost the entire section is composed of dark gray shales and shaly sandstones. Much of the formation is barren of fossils, but a few key beds may be traced with some accuracy throughout the outcrop area. Less complete sections of Pierre may be measured in the park areas of central Colorado. In these areas the upper part of the formation has been removed, either by erosion or faulting, so that the maximum thickness now present is 5,000 feet. These sections also yield fossils from a few beds. The thick Mancos and Mesaverde formations in western Colorado differ greatly in lithologic characteristics from the Pierre, but similar faunal horizons may be determined in some areas.

¹ Presented in part before the Rocky Mountain Section of the Geological Society of America, Boulder, Colorado, April 23, 1949. Manuscript received, April 27, 1949.

² Instructor in geology, University of Colorado.

PREVIOUS STUDIES OF PIERRE STRATIGRAPHY

The most recent attempt to subdivide the Pierre shale in Colorado was made by Dane, Pierce, and Reeside³ in the area north of the Arkansas River in the eastern part of the state. In this area they propose to apply only one formal member name, the "Sharon Springs shale member," for the basal zone. For the rest of the formation only informal names are used, in ascending order: "rusty zone," "tepee zone," and "transition zone." These zone terms are recognized and used as formal stratigraphic names in the present paper.

The Sharon Springs shale member as defined by Dane, Pierce, and Reeside is a widespread homogeneous unit of black clay shale, 155 feet thick, which conforms lithologically with the Barren zone previously recognized by Gilbert⁴ in the vicinity of Pueblo, and by Lavington⁵ in the Cañon City-Florence district. Both are, as the latter name implies, almost entirely devoid of fossils. The Sharon Springs shale zone of Colorado may be correlated with the Sharon Springs of Elias⁶ in northwest Kansas on the basis of lithologic character, the presence of fish scales, and its position at the base of the Pierre.

The "rusty zone" of Dane, Pierce, and Reeside⁷ consists of "brownish-gray and dark-gray shales, with numerous reddish-brown calcareous beds and small flattish red-brown concretions." Gilbert⁸ recognized this zone and differentiated at its top a "Baculite zone, 100-200 feet thick" which "is pale gray and is so-called from the abundance of a fossil shell of that name." Lavington also recognizes the rusty zone but does not believe that the "Baculite zone" of Gilbert is persistent over widespread areas in northeastern Colorado. Elias has recognized three members overlying the Sharon Springs member in northwest Kansas: the Weskan member, overlain by the Lake Creek member, which in turn is overlain by the Salt Grass member. These are correlated by Dane, Pierce, and Reeside with the "rusty zone" of eastern Colorado. Elias suggests that the Salt Grass member in northwest Kansas is equivalent to the "Baculite zone" in the Arkansas Valley in Colorado.

The Tepee zone is, according to Dane, Pierce, and Reeside,⁹ "distinguished by the presence of 'tepee buttes'—small sharply conical hills, formed by the superior resistance to weathering of large concretionary masses of limestone." Gilbert defines it as a zone 1,000 feet thick, overlying the "Baculite zone" and

³ C. H. Dane, W. G. Pierce, and J. B. Reeside, Jr., "The Stratigraphy of the Upper Cretaceous Rocks North of the Arkansas River in Eastern Colorado," *U.S. Geol. Survey Prof. Paper 186 K* (1937).

⁴ G. K. Gilbert, "Pueblo, Colorado," *U. S. Geol. Survey Geol. Atlas Folio 36* (1897).

⁵ C. S. Lavington, "Montana Group in Eastern Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 4 (1933), p. 397.

⁶ M. K. Elias, "Geology of Wallace County, Kansas," *Kansas Geol. Survey Bull.* 18 (1931).

⁷ C. H. Dane, W. G. Pierce, and J. B. Reeside, Jr., *op. cit.*, p. 224.

⁸ G. K. Gilbert, *op. cit.*, p. 3.

⁹ C. H. Dane, W. G. Pierce, and J. B. Reeside, Jr., *op. cit.*, p. 226.

including all of the upper part of the Pierre as exposed in the Pueblo Quadrangle. In northwest Kansas, Elias notes a zone of "undifferentiated shale" overlain by the Beecher Island member. He correlates both with the lower part of the Tepee zone of Colorado.

Above the Tepee zone is a zone which is "lithologically a transition unit from the dominantly fine sedimentary beds of the Pierre shale to the sandstone of the Fox Hills."¹⁰ It is composed of sandy shale and soft sandstone and has been recognized in almost all previous reports.

In the Missouri Valley in South Dakota, W.V. Searight¹¹ has attempted the subdivision of the Pierre shale at the type locality. Here he recognizes in ascending order: (1) the Gregory member; (2) the Sully member, including the Agency shale, Oacoma zone, and Verendrye beds; (3) the Virgin Creek member; (4) the Mobridge member; and (5) the Elk Butte member. Of these Searight correlates the lower Gregory with the Sharon Springs of Elias in northwest Kansas, and with the lower part of the Pierre of Colorado; the Oacoma beds with the lower Weskan of Kansas; the Mobridge with the Beecher Island shale of Kansas.

In 1905, Fenneman¹² briefly discussed the Pierre stratigraphy in the vicinity of Boulder, Colorado. In this discussion he noted the presence of the Hygiene sandstone member "forming a strong ridge which is almost continuous for many miles. The ridge passes within a mile and a half of the village of Hygiene, where the sandstone is typically developed." Although Fenneman recognized only one persistent sandstone, he suggested "that there is more than one bed, and it is probable that the beds occur at any horizon and are of very limited lateral extent."

Junius Henderson,¹³ in 1908, collected and described an extensive fauna from the "Hygiene sandstone" at Fossil Ridge. He followed Fenneman in assuming the presence of only one dominant sandstone member in the Pierre and correlated the Fossil Ridge sandstone with the "Hygiene sandstone" of Fenneman.

In northeastern Colorado, Ball¹⁴ divided the Pierre into Steele shale at the base, Mesaverde, and Lewis. The Mesaverde is divided into five sandstones, namely from oldest to youngest, the Hygiene, the Terry, the Rocky Ridge, the Larimer, and the Richard.

LITHOLOGY OF PIERRE SHALE IN NORTHERN COLORADO

The Pierre shale along the foothills of the Front Range in northern Colorado

¹⁰ *Ibid.*, p. 229.

¹¹ W. V. Searight, "Lithologic Stratigraphy of the Pierre Formation of the Missouri Valley in South Dakota," *South Dakota Geol. Survey Rept. Investig.* 27 (1937).

¹² N. M. Fenneman, "Geology of the Boulder District, Colorado," *U. S. Geol. Survey Bull.* 265 (1905), pp. 31-33.

¹³ Junius Henderson, "The Sandstone of Fossil Ridge in Northern Colorado and Its Fauna," *Colorado Univ. Studies*, Vol. 5 (1908), pp. 179-92.

¹⁴ M. W. Ball, "Gas Near Fort Collins, Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 1 (1924), pp. 78-87.

DETAILED SECTION OF PIERRE FORMATION MEASURED BY PLANE TABLE AT ROUND BUTTE,
SEC. 19, T. 11 N., R. 68 W., LIVERMORE QUADRANGLE, COLORADO

Unit	Thickness (Feet)
Transition zone	
29 Sandy shale, soft, buff, brown, and light gray, with several thin limestone and sandstone beds, mostly covered	4,000
Hygiene zone	
Richard sandstone member	
28 Sandstone, buff, weathering rusty, medium-grained, barren	3
27 Shaly sandstone, light buff, grading vertically into sandstone	8
26 Soft sandstone, buff, thick-bedded, barren, fine-grained; near top is shale parting $\frac{1}{2}$ -inch thick with hard rusty concretions	9
25 Soft shaly sandstone, buff, fine-grained	8
24 Soft sandstone, buff, with very large (4-foot diameter) hard rusty concretions, barren	10
23 Alternating yellow buff shaly sandstone and buff sandstone with large concretions	20
Total Richard sandstone	58
Larimer sandstone member	
22 Gray-brown sandstone, weathering dark red, medium-grained, hard, <i>Haly-menites</i>	3
21 Sandstone, gray-buff, soft, barren	9
20 Gray-brown sandstone, weathering dark red	2
19 Soft sandy shale, gray-buff	14
18 Gray-brown sandstone, weathering dark red	3
17 Buff sandy shale, soft	11
16 Gray-brown sandstone, weathering dark red	4
15 Sandy shale, covered	12
14 Gray-brown sandstone, weathering dark red, barren except <i>Haly-menites</i>	2
13 Sandy shale, covered	10
Total Larimer sandstone	70
Rocky Ridge sandstone member	
12 Sandstone, yellow-buff, medium-grained, thick-bedded, highly fossiliferous, hard	20
11 Sandy shale, soft, buff	1
10 Sandstone, yellow-buff, massive, fossils scarcer and poorer than in upper sandstone	47
9 Sandy shale, covered	50
Total Rocky Ridge sandstone	118
Terry sandstone member	
8 Sandstone, buff, weathering rusty, barren, massive, a few concretions	10
7 Alternating buff sandstone and sandy shale	80
6 Alternating soft yellow sandstone and sandy shale, covered	600
Total Terry sandstone	690
Hygiene sandstone member	
5 Yellow-buff sandstone, thick-bedded, cross-bedded near top, medium-grained, barren	20
4 Soft buff sandstone, mostly covered	180
Total Hygiene sandstone	200
Total Hygiene group	1,136
Rusty zone	
3 Dark gray shale, weathering in rounded fragments, abundant <i>Baculites</i> ("Baculite member")	200
2 Dark gray shale, soft, friable, numerous rusty concretions, thin bentonite beds	1,000
Sharon Springs zone	
1 Shale, dark gray, fissile, barren, mostly concealed	425
Total Pierre formation	6,761

ZONES OF PIERRE FORMATION OF COLORADO 2015

DETAILED SECTION OF PIERRE FORMATION MEASURED BY PLANE TABLE WEST OF BERTHOUD,
SEC. 17-18, T. 4 N., R. 69 W., LOVELAND QUADRANGLE, COLORADO

Unit	Thickness (Feet)
Transition zone	
15 Covered, sandy soil.....	5,000
Hygiene zone	
Larimer sandstone member	
14 Soft sandstone, thin-bedded, sparsely fossiliferous.....	132
13 Soft sandstone, light buff, thin-bedded.....	4
Total Larimer sandstone.....	136
Rocky Ridge sandstone member	
12 Covered, sandy soil, four small tepee buttes showing red-brown hard concretions, fossiliferous.....	268
Terry sandstone member	
11 Covered, probably sandy shale.....	150
Hygiene sandstone member	
10 Buff sandstone, hard, ridge-forming, barren, weathering rusty, medium-grained, massive, cross-bedded near top.....	50
9 Covered, probably sandy shale.....	30
8 Sandstone, buff, medium-grained.....	2
7 Covered, probably sandy shale.....	10
6 Thin-bedded, dark brown, sandstone.....	2
5 Covered shale.....	20
4 Sandstone, thin-bedded, brown, soft.....	3
Total Hygiene sandstone.....	117
Total Hygiene zone.....	671
Rusty zone	
3 Dark gray shale, weathering in rounded fragments, abundant <i>Baculites</i> ("Baculite member").....	150
2 Dark gray shale, friable, soft, covered.....	1,100
Sharon Springs zone	
1 Shale, very dark gray, fissile, barren.....	500
Total Pierre formation.....	7,421

ranges in thickness from 5,000 to 8,000 feet. The lithologic and faunal characteristics of the formation between the Wyoming border and Boulder remain remarkably uniform. The following sections of the Pierre indicate the greatest variations in lithologic character in this area.

In the foothills region, the base of the Pierre can be readily recognized in its contact with the Niobrara. The basal Sharon Springs shale zone is composed of very black, fissile, finely laminated shale with many lenses of bentonite. The contact can be detected at some distance as the Pierre is very easily eroded and crops out only as a black wash on the dip slope of the yellow sandstone of the upper Niobrara. Farther out in the Denver basin, where the yellow Niobrara member is missing, the contact is so gradational as to be difficult to determine in well cuttings.

The Sharon Springs shale zone is very easily eroded and outcrops are few. In some places it is partly exposed in small gullies. The basal part of the Pierre and the underlying Niobrara dip generally eastward 15° - 28° , the dip diminishing eastward. The thickness of the Sharon Springs zone ranges from 400 to 500 feet.

Overlying this zone is a section of 1,200 feet of dark shales. These may be

divided arbitrarily into two parts. The lower part is ordinarily covered, but, where exposed, it shows black, flaky shale, not as fissile as the Sharon Springs zone, but very soft. These shales also contain thin bentonite beds and a few rusty concretions. They grade upward into harder, dark gray shale which characteristically breaks into small rounded fragments. In this upper part of the shale beds are many large rusty, flat concretions and lenses. This is the zone known as the Rusty zone in eastern Colorado.

The upper part of the Rusty zone is sandy and grades through a transitional contact into the lowest of the Hygiene sandstones. This sandstone, the Hygiene sandstone proper, 200 feet thick, is composed of thin, drab brown and buff sandstones and sandy shales with thick, massive, cross-bedded, buff sandstone at the top. This uppermost cross-bedded sandstone of the Hygiene forms a clear-cut horizon marker where exposed and commonly crops out in a prominent ridge. This is the sandstone originally referred to as the entire Hygiene by Fenneman.¹⁵

Overlying the Hygiene sandstone are alternating soft buff sandstones and sandy shales averaging 350-400 feet thick. These are not resistant to erosion and are generally inconspicuous. In the vicinity of Terry Lake, 3 miles north of Fort Collins, these beds are well exposed and are composed of soft, buff, cross-bedded sandstone at the base, overlain by thin sandstones and gray shales. At the top is buff to yellow, medium-bedded sandstone. This Terry sand member is much softer than the other members and is not a ridge-former.

North of Loveland, Colorado, the most conspicuous member of the Hygiene zone is the Rocky Ridge sandstone. This member forms Fossil Ridge, 5 miles south of Fort Collins, and Rocky Ridge, 5 miles north of Fort Collins. This is the sandstone originally referred to as the entire Hygiene by Henderson. Wherever it is well developed, it is a ridge-former. It is a yellow-buff, medium-grained sandstone, ordinarily thick-bedded. It may be subdivided into two units. The lower unit contains large, round concretions and is light buff. Overlying this unit is massive sandstone characteristically rusty in color due to weathering, and yellow on fresh exposures. These are separated by 6 inches of buff sandy shale. Together they have an average thickness of approximately 200 feet. This sandstone is topographically less conspicuous south of Loveland and is progressively more shaly on the south.

The Larimer sandstone is a series of gray-buff sandy shales and thin sandstone layers which characteristically weather dark red. These beds form a ridge locally, as on the east side of U.S. highway 87 and 287 at Fossil Ridge, and $\frac{1}{2}$ mile east of Waverly, Colorado. More commonly they crop out on the dip slope of the underlying Rocky Ridge sandstone.

The Richard sandstone member in the Fort Collins region is composed of alternating massive soft buff sandstones and shaly sandstones. The sandstone beds contain large hard rusty concretions. This member is not conspicuous topographically and is rarely well exposed. The best outcrops noted were at the Round

¹⁵N. M. Fenneman, *op. cit.*

Butte locality. The member dies out southward and is not recognizable south of Lonetree Reservoir, 4 miles south of Loveland, Colorado.

The upper Pierre of northern Colorado is not well exposed at many localities along the foothills. It is composed of buff to yellow, soft sandy shale, with some thin sandstone beds. The uppermost sandstone member of the Hygiene zone, the Richard sandstone on the north and the Larimer sandstone south of Loveland, grades upward into the softer shaly sandstones of the Transition zone of the upper Pierre. This, in turn, grades through a transitional contact into the yellow-green sandstone of the Fox Hills formation.

FAUNA OF PIERRE SHALE IN NORTHERN COLORADO

The Pierre shale contains an extensive fauna of invertebrates. This fauna, however, is not evenly distributed throughout the formation. Most of the invertebrates are confined to a single bed in the Hygiene zone.

The Sharon Springs shale zone or Barren zone is almost completely devoid of fossil remains with the exception of fragmentary fish scales. This is true in all regions where the zone is recognized in Colorado and bordering states. Pyrite is common in the zone and yellow sulphur is commonly found between the thin shale layers.

The Rusty zone, as mentioned, is tentatively divided into two units. The lower dark shale unit contains very little fossil material. A few crushed specimens of *Baculites ovatus* Say were noted and a few specimens of *Inoceramus sagensis* Owen. The upper harder gray shale unit contains many specimens of *Baculites ovatus* Say, *Baculites ovatus* var. *harsi* Reeside, *Inoceramus barabini* Morton, and *Inoceramus sagensis* Owen. The large number and concentration of baculite remains in this unit suggest correlation with the "Baculite zone" of Gilbert.

The Hygiene sandstone proper is almost barren. Specimens of *Halymenites* are noted, but as this genus ranges throughout the Pierre and Fox Hills it is not of diagnostic value. The overlying Terry sandstone contains a few poorly preserved specimens of *Inoceramus* which are too badly crushed and fragmentary for specific identification.

The Rocky Ridge sandstone member of the Hygiene zone contains the most abundant and diversified fauna in the Pierre. Although this sandstone has been divided into two units lithologically, these units are not separable paleontologically. The following species are recognized in this member.

Inoceramus incurvis Meek and Hayden
Inoceramus barabini Morton
Inoceramus vanuxemi Meek and Hayden
Inoceramus sagensis Owen
Inoceramus proximus Tuomey
Inoceramus altus Meek
Inoceramus balchii Meek and Hayden
Inoceramus tenuilineatus Hall and Meek
Pinna lakesii White
Volsella meekii Evans and Shumard
Veniella humilis Meek and Hayden

Ostrea falcata Morton
Ostrea inornata Meek and Hayden
Lucina occidentalis Morton
Anomia raeliformis Meek
Volutoderma clatworthyi Henderson
Panopaea berthoudi (White)
Callista deweyi Meek and Hayden
Syncyclonema rigida Hall and Meek
Pteria linguiformis Evans and Shumard
Anchura americana Evans and Shumard
Anchura haydeni White
Thracia gracilis Meek and Hayden
Gyrodes crenata Conrad
Gyrodes abyssina Morton
Fasciolaria culbertsoni Meek and Hayden
Margarita nebrascensis Meek and Hayden
Anisomyon patelliformis Meek and Hayden
Anisomyon borealis Morton
Anisomyon centrale Meek
Turritulites sp.
Dentalium gracile Hall and Meek
Baculites compressus Say
Baculites ovatus var. *haresti* Reeside
Acanthoscaphites nodosus var. *plenus* (Meek and Hayden)
Acanthoscaphites nodosus var. *brevis* (Meek)
Acanthoscaphites nodosus var. *quadrangularis* (Meek and Hayden)
Placenticeras intercalare (Meek and Hayden)
Placenticeras meeki Boehm
Eutrechoceras dekayi (Morton)
Exileloceras jenneyi (Whitfield)
Solenoceras sp.
Solenoceras crassum (Whitfield)
Solenoceras mortoni Meek and Hayden
Helicoceras sp.
Heteroceras sp.
Hamites sp.
Terebratulula sp.

This invertebrate fauna includes most of the species described in the Tepee zone of southeastern Colorado. Wherever this sandstone is well exposed, it is found to be extremely fossiliferous. In the lower concretion-bearing unit most of the fossils are found in the hard round concretions. In the upper unit, the fossils are found in layers which may be composed entirely of pelecypod shells.

The overlying Larimer sandstone is also fossiliferous. Fossils are abundant and include several different genera.

Inoceramus balchii Meek and Hayden
Inoceramus barabini Morton
Inoceramus sagensis Owen
Inoceramus proximus Tuomey
Pteria linguiformis var. *subgibbosa* (Meek and Hayden)
Ostrea patina Meek and Hayden
Anisomyon borealis (Morton)
Baculites compressus Say
Acanthoscaphites nodosus var. *plenus* (Meek and Hayden)
Hamites (?) sp.

The specimens in this member are neither as well preserved nor as abundant as those in the Rocky Ridge member. The most common species are *Baculites compressus* Say, *Inoceramus barabini* Morton, and *Inoceramus sagensis* Owen.

The Richard sandstone member is barren in all the outcrops examined. Due to poor outcrops, the Transition zone did not yield many fossils. Where it was exposed, however, specimens of the following genera were abundant: *Lucina*, *Mastra*, *Inoceramus*, *Ostrea*, *Crassatella*, *Callista*, and *Acanthoscapiles*.

CORRELATION OF PIERRE SHALE OF FOOTHILLS
WITH OTHER AREAS OF COLORADO

Comparison of the sections measured in the foothills with those of other areas of Colorado shows a close similarity between faunal zones. The lithologic character is more variable. Through comparison with faunal lists of Dane, Pierce, and Reeside the sections in the northern foothills can be correlated with the stratigraphic subdivisions recognized in eastern Colorado.

In eastern Colorado, the basal 550 feet of thin-bedded dark gray shale of the Pierre section is assigned to the Sharon Springs shale zone. This is correlated with 500 feet of very dark gray fissile shale overlying the Niobrara in the foothills area. Throughout both areas these beds are almost devoid of fossil remains. Fish scales and a few poorly preserved specimens of *Baculites* are recorded. Close similarity in lithologic character and position in the section suggest correlation.

Overlying the Sharon Springs shale zone, 1,000 feet of dark gray shale is recorded in the foothills area. Most of this section is concealed. Therefore, exact lithologic characteristics are not known. Few fossils are noted. Where outcrops are found, the shales contain rusty concretions and bentonite layers. These beds and the overlying 150-200 feet of dark gray, slightly harder shale are assigned to the Rusty zone of eastern Colorado. The Sharon Springs shale zone may extend higher in the section than here suggested and the Rusty zone may be less than 1,150-1,200 feet thick. The contact is gradational and exposures are few. The upper harder shale zone contains many specimens of *Baculites ovatus* Say. This zone is correlated with the "Baculite zone" of Gilbert. It is not a mappable unit in the foothills area.

Correlation of the Hygiene zone of sandstones and sandy shales of the foothills area with the strata directly overlying the Rusty and "Baculite" zones in eastern Colorado is more difficult. Many geologists have noted a Tepee zone in eastern Colorado. Lavington¹⁶ notes that a second zone of smaller tepee buttes is recognized 300-700 feet above the main series southeast of Hugo, Colorado. This zone contains a fauna including *Lucina occidentalis* Morton and many small gastropods. Below this zone in which the tepee buttes occur are 200-600 feet of shale. The tepee buttes are also embedded in dark shale. The section of Pierre shale above the Tepee zone is composed of sandy shale and soft sandstone. Lithologically this section of shales bears little resemblance to the section of sandstones and sandy shales of the foothills of northern Colorado. There is a striking similarity between the faunas of the two areas. The Hygiene zone of northern Colo-

¹⁶ C. S. Lavington, "Montana Group in Eastern Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 4 (1933), p. 402.

rado consists of three to five sandstones with intervening shales. As noted, the third or Rocky Ridge sandstone contains a very diversified fauna. This fauna closely resembles the fauna of the lower tepee buttes of Lavington. Furthermore, $3\frac{1}{2}$ miles west of Berthoud, Colorado, there are five small tepee buttes in the Hygiene zone. Also on the north side of Lonetree Reservoir, 3 miles northwest of Berthoud, Colorado, another small tepee butte is noted. These tepee buttes are 260 feet stratigraphically above the base of the Hygiene zone. The lowest sandstone member, the Hygiene sandstone proper, is well developed in this locality and is 117 feet thick. The characteristic uppermost sandstone of this lowest member, a hard, ridge-forming, cross-bedded sandstone, is readily recognized. Above this member are concealed beds, probably sandy shale, which are assigned to the Terry member. A soft sandstone containing the characteristic, meager fauna of the Larimer member is exposed in a road cut $3\frac{1}{2}$ miles west of Berthoud, Colorado. This sandstone crops out 1,250 feet east of the Hygiene member proper. Between the Terry and the Larimer members in all exposures north and south of this area is a well developed sandstone, the Rocky Ridge member. In this area just west of Berthoud, tepee buttes with the characteristic Rocky Ridge fauna occur between the Larimer and the Terry sandstones. The tepee buttes are apparently embedded in sandy shale or shale, but no exposures of the surrounding rocks are available. The area is under cultivation and the tepee buttes occur in a plowed field, suggesting that the material surrounding the buttes is soft and has little resistance to erosion.

Further proof that the Tepee zone of eastern Colorado should be correlated with the Rocky Ridge member of the Hygiene zone of northern Colorado is the presence of round hard concretions in the tepee buttes west of Berthoud and the characteristic occurrence of numerous large concretions in the Rocky Ridge member wherever it is typically exposed.

The sandstone members above and below the Rocky Ridge member are tentatively correlated with the shales of eastern Colorado overlying and underlying the Tepee zone. No fauna has been recorded from the shales between the Tepee zone and the Rusty zone in eastern Colorado, nor is one found in the foothills of northern Colorado between the Rusty zone and the Rocky Ridge member of the Hygiene zone. The Larimer sandstone may be tentatively correlated with the upper Tepee zone of Lavington on the basis of similarity of fauna and stratigraphic position.

Above the Tepee zone Lavington¹⁷ recognizes a "Cone-in-cone zone." This is a zone in which cone-in-cone beds are

more prevalent in, and rather characteristic of, the gray clay shale zone lying between the main Tepee butte series and the Transition zone above. Besides the cone-in-cone beds, these shales contain ironstones similar to those of the Rusty zone (but not as numerous), limy concretion beds, and in places, thin sandstones, and a few bentonite beds.

Although cone-in-cone beds are recognized at various horizons in the Pierre,

¹⁷ C. S. Lavington, *op. cit.*, p. 403.

no zone comparable with that described by Lavington is found in the foothills of northern Colorado.

The Transition zone is defined by Lavington¹⁸ as the zone which "includes the beds which lie between the mappable group of sandstones and sandy concretion beds of the Fox Hills sandstone, as now defined, and the lower beds which contain typical Pierre fossils." The Transition zone exposed in the foothills of northern Colorado occupies a similar stratigraphic position.

Correlation of the Pierre shale section of the foothills and eastern Colorado with the Pierre and its age equivalents of western Colorado is less certain. A section measured by Arthur Richards¹⁹ near Kremmling, in Middle Park, Colorado, helps bridge the gap between the continental and brackish-water series of western Colorado and the marine Pierre of eastern Colorado. An approximate correlation may be established between the Middle Park Pierre and the Pierre of northeastern Colorado.

The following composite section of Pierre shale was measured near Kremmling, Colorado, by Arthur Richards (1940). The fossils were identified by the writer.

Unit	Thickness (Feet)
28 Covered by gravel.....	100
27 Black clay shale, non-calcareous.....	80
26 Massive to medium-bedded sandstone, light gray, weathers tan to brown, cross-bedded locally, non-calcareous.....	35
25 Largely covered, black shale where exposed.....	400
24 Calcareous sandstone, brown, concretionary, fossiliferous.....	2
23 Sandy shale.....	5
22 Calcareous sandstone, concretionary, brown, fossiliferous. <i>Platoniceras meeki</i> , <i>Inoceramus sagensis</i> , <i>Inoceramus altus</i> , <i>Inoceramus proximus</i> , <i>Baculites compressus</i> , <i>Acanthoscaphites nodosus</i> var. <i>plenus</i> , <i>A. nodosus</i> var. <i>brevis</i> , <i>A. nodosus</i> var. <i>quadrangularis</i> , <i>Heteroceras</i> sp. in both this and unit 24.....	6
21 Covered black shale.....	250
20 Interbedded black shale and sandy limestone, fossiliferous, gray, weathers brown.....	40
19 Covered black shale.....	400
18 Sandstone, calcareous, grayish tan, massive to thin-bedded.....	50
17 Covered black shale.....	250
16 Gray sandstone, weathers tan, thin-bedded at base, medium-bedded at top, with <i>Inoceramus sagensis</i> , <i>Inoceramus proximus</i> , <i>Baculites compressus</i> , <i>Baculites ovalis</i> var. <i>haresti</i> , <i>Acanthoscaphites nodosus</i> var. <i>plenus</i>	35
15 Thin-bedded and cross-bedded calcareous sandstone and shaly sandstone.....	40
14 Massive gray sandstone, weathers tan.....	60
13 Largely covered, small exposures of black clay shale, a few thin sandstone layers, a 3-inch limestone, <i>Baculites compressus</i> near middle.....	1,200
12 Shaly sandstone, gray, non-calcareous, weathers tan, with <i>Inoceramus</i> cf. <i>barabini</i> , <i>Baculites ovalis</i> var. <i>haresti</i> , <i>Baculites</i> sp. in this unit and units 7, 8, 9, 10 and 11.....	90
11 Black clay shale.....	60
10 Limestone, tan, dense, weathers yellow.....	1
9 Black clay shale, non-calcareous.....	80
8 Gray sandy shale.....	25
7 Tan shaly sandstone, becoming more sandy in upper part.....	100
6 Black fissile shale and few thin sandstone layers.....	120
5 Black sandy shale, non-calcareous.....	10
4 Shaly sandstone, gray, weathers tan.....	50
3 Covered, probably shaly sandstone.....	300
2 Black shale.....	50
1 Black, non-calcareous shale, mostly covered.....	1,100
Total Pierre shale.....	4,939

¹⁸ *Ibid.*

¹⁹ Arthur Richards, unpublished thesis, University of Michigan (1940).

At the base of the section in Middle Park are 1,150 feet of black, non-calcareous shale which is assigned to the Sharon Springs shale zone. The overlying 2,036 feet of dark shale and shaly sandstone are tentatively assigned to the Rusty zone. This zone contains a limited fauna very similar to that of the Rusty zone of eastern Colorado. No distinct concentration of *Baculites* remains is noted at any point in this zone. Overlying this Rusty zone are 1,573 feet of thin sandstones and interbedded shales. These sandstones are like the Hygiene sandstone zone of the foothills of eastern Colorado, both in their position in the section and in their faunal content. Units 14 and 15 at the base of this zone are assigned to the Hygiene sandstone proper on the basis of stratigraphic position, general lithology and the cross-bedded upper unit. No fossils are known from these units. A third of the distance from the top of the zone of sandstones and shales are two thin calcareous sandstones, units 22 and 24, bearing large concretions and a rich fauna. This fauna includes many of the species noted in the Rocky Ridge member of the Hygiene zone. The concretionary character of the sandstone together with the fauna suggest correlation of these fossiliferous sandstones with the Rocky Ridge sandstone member. Unit 26 is correlated provisionally with the Larimer member in eastern Colorado. Overlying the Hygiene zone is 80 feet of black clay shale. It is probable that this 80 feet is the lowest part of the Transition zone. The overlying beds were apparently removed prior to the deposition of the Middle Park formation.

Other sections of the Pierre shale in central Colorado indicate that the faunal and lithologic zones recognized in eastern Colorado and Middle Park may be extended into the North and South Park areas. As in Middle Park, the Transition zone has been removed by erosion. The Sharon Springs and Rusty zones are typically developed, although not well exposed. Overlying the gray shales of the Rusty zone, a section of sandstones and sandy shales referred to the Hygiene was measured on the east side of the McCallum anticline, T. 8 N., R. 76 W., Secs. 2-3, Jackson County, Colorado.

Unit	Thickness (Feet)
10 Covered, probably dark gray sandy shale, <i>Inoceramus</i> present, not common.....	100
9 Sandstone, buff, weathering red, massive, soft, numerous <i>Halymenites</i> , <i>Crassatellites</i> , <i>Inoceramus</i>	20
8 Sandstone, gray, weathering brown, thin-bedded.....	2
7 Sandstone, gray-buff and soft shaly sandstone.....	6
6 Sandstone, buff.....	1
5 Sandy shale.....	11
4 Sandy shale, gray, soft, mostly covered with one sandstone 15 feet from top.....	100
3 Sandstone, buff, weathering yellow, massive, soft, highly fossiliferous in pockets and concretions.....	24
2 Sandstone, buff, weathering red, fossiliferous.....	22
1 Gray sandy shale, covered, base not exposed	

Units 2 through 9 of this section are referred to the Hygiene. Units 2 and 3 contain a very extensive fauna, including the following species.

Inoceramus barabini Morton
Inoceramus sagensis Owen
Inoceramus vanuxemi Meek and Hayden
Inoceramus incurvis Meek and Hayden
Inoceramus balchii Meek and Hayden
Pinna lakesii White
Lucina occidentalis Morton
Veniella humilis Meek and Hayden
Endocostea typica Whitfield
Lucina subundata Hall and Meek
Ostrea patina Meek and Hayden
Volsella sp.
Margarita nebrascensis Meek and Hayden
Dentalium gracile Hall and Meek
Exileceras jenneyi (Whitfield)
Hamites sp.
Solenoceras crassum (Whitfield)
Solenoceras sp. aff. *crassum*
Heteroceras umbilicatum Meek and Hayden
Heteroceras sp.
Helicoceras rubeyi Reeside
Baculites compressus Say
Baculites ovalis var. *harsi* Reeside
Acanthoscaphites nodosus var. *brevis* (Meek)
Placentoceras sp.

Almost all of these species are found commonly in the Rocky Ridge member of the Hygiene zone along the Front Range. On the basis of this similarity in fauna and general lithologic character, the horizons are considered equivalent. Unit 9 of the North Park section is sparingly fossiliferous and is tentatively correlated with the Larimer sandstone of the Front Range on this basis, and on lithologic character and stratigraphic position.

In South Park a similar section is found. The Sharon Springs and Rusty zones are typically developed. The Rocky Ridge member of the Hygiene zone is recognized on the basis of fauna and lithology, and an upper sandstone is referred to the Larimer member. The Transition zone has been removed by erosion. The proposed correlation of the Hygiene zone in eastern and central Colorado is shown in Figure 1.

Correlation of parts of the Mesaverde and Mancos formations with the Pierre is difficult due to the change in sedimentation on the west. Some correlations are suggested on the basis of scattered fossil collections and sections. Much more work is needed for accurate, detailed correlation.

In Moffat County, northwestern Colorado, a study of exposed Mancos and Mesaverde yields fossil zones comparable with those of eastern Colorado. The Mancos shale in this area is approximately 5,000 feet thick. The lowest part of this formation contains Benton and Niobrara faunas and is overlain by a series of barren dark shales and shaly sandstones which may be correlated provisionally with the Sharon Springs zone of the Pierre. Approximately 800 feet below the top of the Mancos is a persistent series of thin-bedded barren sandstones called the Morapos sandstone member by Hancock.²⁰ In the 400-500 feet of dark shale di-

²⁰ E. T. Hancock, "Geology and Coal Resources of the Axial and Monument Butte Quadrangles, Moffat County, Colorado," *U. S. Geol. Survey Bull.* 757 (1925), p. 12.

rectly overlying the Morapos sandstone member of the Mancos, numerous specimens of *Baculites ovatus* Say and poorly preserved specimens of *Inoceramus* occur. The fossils generally are found in hard, calcareous, septarian concretions. In addition to the calcareous concretions, there are many rusty concretions and

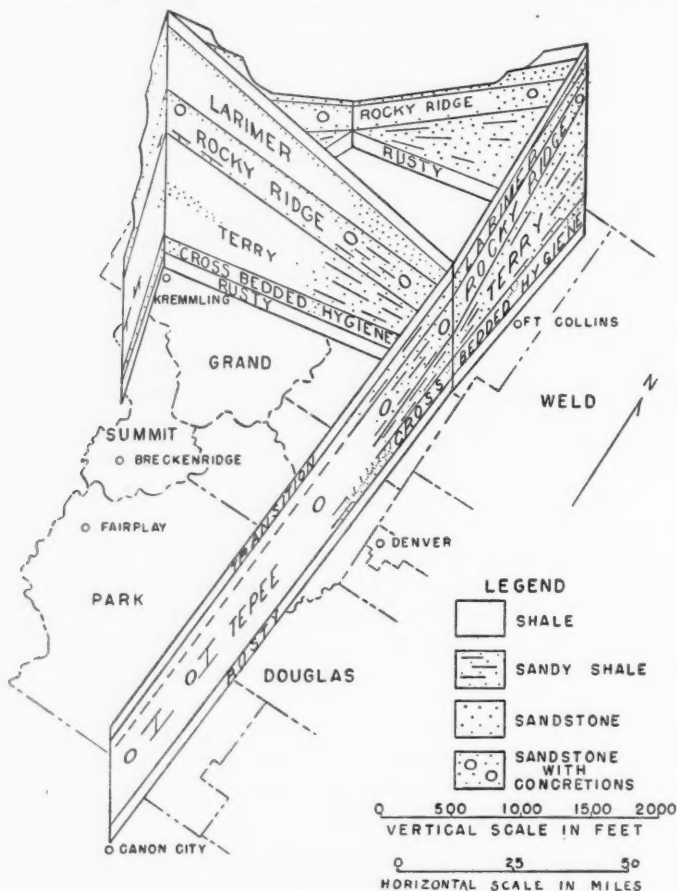


FIG. 1.—Correlation of sandstone members of Hygiene zone in eastern and central Colorado.

lenses. This zone closely resembles the Rusty zone of eastern Colorado both in lithologic character and fauna.

Overlying the Mancos formation is the Iles formation of the Mesaverde group. This formation consists of a series of soft sandstones and sandy shales in the lower part, overlain by hard light-colored sandstones. In the lower 100 feet of the Iles

formation in a series of shales between the basal shaly sandstone and a strong sandstone cap rock, a faunal zone contains abundant specimens of *Inoceramus barabini* Morton, *Inoceramus sagensis* Owen, *Inoceramus vanuxemi* Meek and Hayden, *Lucina occidentalis* Morton, *Acanthoscaphites nodosus* (Meek and Hayden), and *Placenticerus meeki* Boehm. This zone occupies a position and contains a fauna similar to that of the Rocky Ridge member of the Hygiene zone.

The uppermost part of the Iles and the Williams Fork contain invertebrates which are tentatively correlated with the Transition zone and overlying Fox Hills. No detailed work has been done with this upper section.

An attempt is made to extend this general correlation into the area of the type section of the Mesaverde group in southwestern Colorado. Here also the upper Mancos has the typical Rusty zone fauna, and the characteristic rusty concretions occur in the upper 200 feet of the dark shales. Overlying the Mancos is approximately 300 feet of Point Lookout sandstone, the lowest member of the Mesaverde formation. Only the top layers of this member are fossiliferous and they contain many fossil leaves, including species of *Salix*, *Viburnum*, and *Ficus*. No invertebrates are recorded from these beds. The middle member of the Mesaverde formation, the Menefee, is composed of 750 feet of sandy shales, carbonaceous shales, and coal beds. The fossils include abundant plant remains including *Sabal*, *Cana*, *Ficus*, *Salix*, *Viburnum*, and unidentified fern leaves. The Menefee yielded no invertebrates. The uppermost member of the Mesaverde formation, the Cliff House sandstone, has an average thickness of approximately 300 feet. It is composed of massive, cross-bedded, yellow sandstone with thin shale partings. The upper 100 feet is very fossiliferous, containing a marine invertebrate fauna similar to the Rocky Ridge fauna of the Hygiene. In this area also, the fossils occur in pockets and concretions, and specimens of *Inoceramus*, *Cardium*, *Crassatellites*, *Baculites*, *Acanthoscaphites*, and *Placenticerus* are locally abundant. The National Park Service has also recorded two small echinoids, a starfish, and many fish fragments from this section. Overlying the Cliff House sandstone is the Lewis shale which contains marine invertebrates of upper Montana age and probably represents the time equivalent of the Transition zone of the Pierre and part or all of the Fox Hills.

It is evident even from such isolated sections that the Mesaverde formation varies greatly in age in Colorado. The Rocky Ridge faunal zone apparently moves down within the sandstones on the north. In southwestern Colorado the Rocky Ridge fauna occurs in the upper 100 feet of the Mesaverde formation, at least 1,200 feet above the Mancos-Mesaverde contact. In northwestern Colorado the same faunal assemblage is found 100 feet above the Mancos-Mesaverde contact. This relationship is shown in the three-dimensional diagram (Fig. 2).

In the preceding discussions, it is assumed that the similar and in large part identical faunas from the various localities represent contemporaneous deposition. However, the possibility must be considered that these may be facies faunas, the result of similar environmental conditions which may have developed in

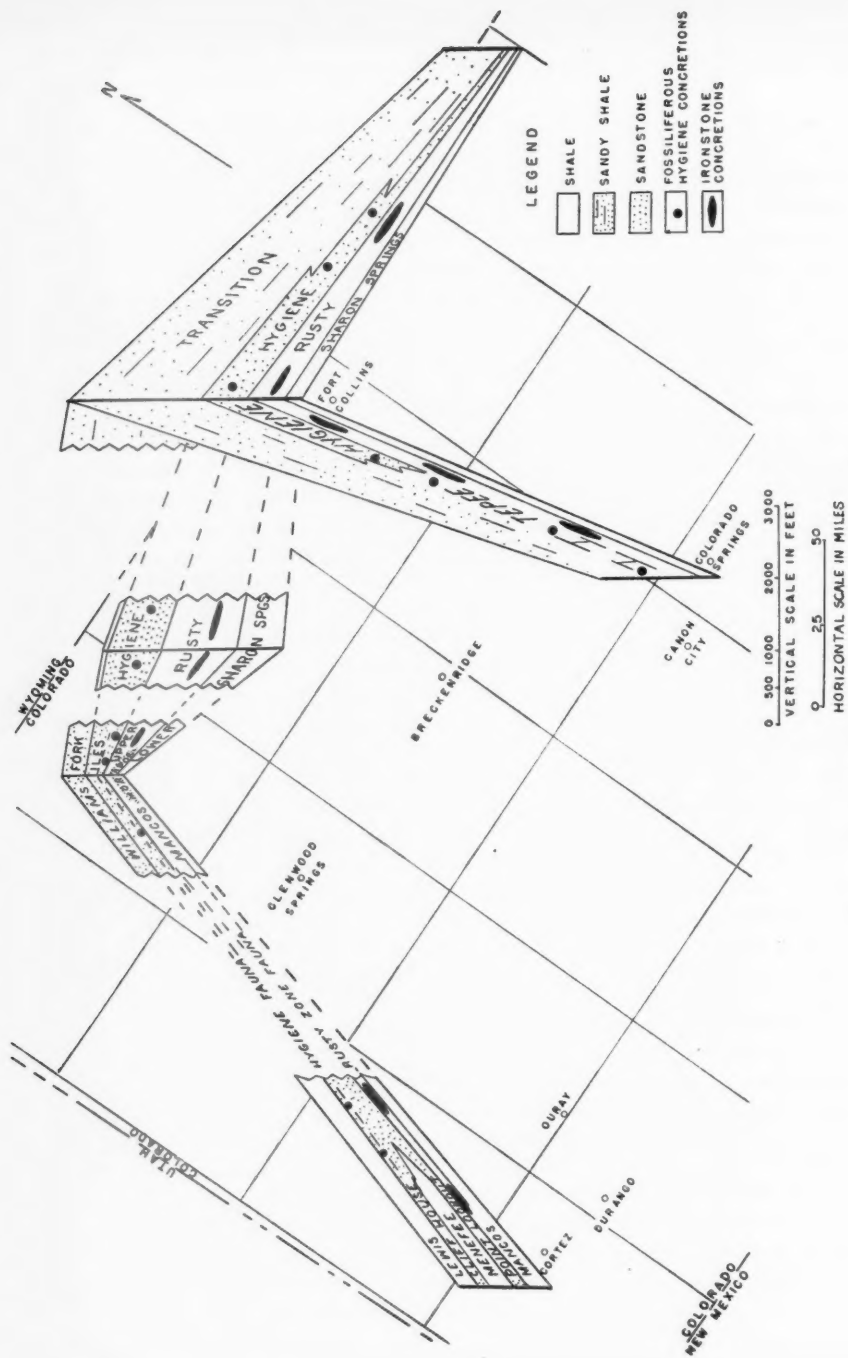


FIG. 2.—Proposed correlation of Pierre zones in Colorado.

separate areas at somewhat different times. If such were the case, one would not expect to find these faunas crossing lateral lithologic boundaries. It has been noted that the Rocky Ridge fauna is typically developed in a sandstone in northern and central Colorado, and that its counterpart is found in the sandstones of the Mesaverde of northwestern and southwestern Colorado. Significantly, this same fauna is also found in the dark calcareous shales of the Colorado Springs-Cañon City area, which represents a different depositional environment.

The cephalopod fauna has been used as the most reliable basis for faunal correlations in this work. Many of these cephalopods were active, rapidly migrating forms which would be expected to have spread rapidly enough within the broad Upper Cretaceous seaway to appear simultaneously in the geologic column. If they had developed separately in isolated environments, or if some forms had persisted much longer in certain areas than in others, at least minor evolutionary changes would be expected to develop in the species. This does not seem to be true. The cephalopods collected from the various localities are in most cases identical species, with little individual variation.

Although the possibility that the faunas described are in part reflections of a peculiar ecological condition can not be completely disproved, the evidence at hand strongly suggests that they were contemporaneous and freely migrating.

CONDITIONS OF SEDIMENTATION

The Pierre formation was deposited during the first stages of withdrawal of the Upper Cretaceous sea from the Rocky Mountain geosyncline. In the earliest part of Pierre time, the sea was probably deep over much of Colorado. Over northwest Kansas, Nebraska, South Dakota, southern Wyoming, and eastern Colorado very dark shales were deposited. The lowest part of these shales is almost barren. In many areas thin beds of bentonite and balls of pyrite and marcasite are found throughout the section. Between thin laminae of the dark shales in the foothills area are coatings of yellow sulphur. The absence of fossils and the presence of considerable quantities of sulphides, together with the very dark color of the shales, suggest an environment of deep quiet water. The lack of fossil remains may be in part due to the distance from shore or, more probably, to conditions which prohibited either the existence or the preservation of animal life.

The western shoreline in lowermost Pierre time must have been in eastern Utah, as the dark marine shales of the Mancos are found as far west as western Colorado and the extreme eastern edge of Utah. The retreat of the sea toward the east progressed very slowly during early Pierre time. The sediments gradually become more sandy and lighter in color. Fossils become increasingly more abundant, indicating better oxygen circulation. Thin beds of sandstone are intercalated between the dark shales, indicating minor oscillations of the sea or slight local uplifts on the west. During this time the sediments of the Rusty zone were deposited.

The transition in a short distance from gray shales of the Rusty zone to the buff sandstones of the Hygiene zone in the foothills indicates an abrupt change in the conditions of sedimentation. This pronounced change is noted only in north-central and northeastern Colorado. The sandstones of the Hygiene grade laterally into the thick shales of eastern and southern Colorado, Kansas, Nebraska, and South Dakota. The sandstones persist on the north in eastern Wyoming where they are known as the Mesaverde formation.

Measured sections of the Hygiene zone and its equivalents in Colorado show that the greatest percentage of sand occurs in Larimer and Weld counties along the northern part of the east flank of the Front Range, and that the sand percentages decrease markedly on the south and east. The sediments of the Hygiene zone in their westward extension thicken decidedly in Middle Park. The percentage of sand in this section, however, is 3-5 per cent less than that in the northern Front Range sections. The quantity of sand also increases west of the Park areas in northwestern Colorado.

This distribution of sand suggests that the Hygiene is not part of a great sheet of sand extending eastward from a shoreline in eastern Utah, as generally pictured but is more probably the detrital sediment washed from an island in approximately the position of the present northern Front Range. Not only is it improbable that the sand from the shoreline in Utah would be carried as far eastward as Larimer and Weld counties and still maintain its uniform texture, but the finer character of the sediment and the higher shale percentage in the park areas, and the coarser sandy sediments 50 miles eastward, suggest a local origin for the Hygiene zone of sandstones of the Front Range.

As this island was eroded, progressively finer material was deposited, and the sandstone and shaly sandstone of the Hygiene grade into the sandy shale of the Transition zone. This zone becomes more sandy toward the top, and deposition of sand is continuous into the overlying Fox Hills sandstone. The Transition zone represents a period of gradual, regular withdrawal of the Pierre sea from the Rocky Mountain geosyncline until the beginning of Fox Hills time when sandstones were deposited in the shallow water across eastern Colorado.

GEOLOGICAL NOTES

CONNELL SANDSTONE, OIL CREEK FORMATION, SIMPSON GROUP, WEST TEXAS¹

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Fort Worth, Texas

A sandstone in the lower part of the Simpson group (Lower and Middle Ordovician) is an important new oil-producing sand for the Central Basin platform geologic province of West Texas.

The Texas Company's W. E. Connell No. 33, in the NE. $\frac{1}{4}$, NE. $\frac{1}{4}$ of Sec. 1, Blk. B-22, Public School Land Survey, Jordan area, Ector County, Texas, was the first well completed in this sand, although other wells in the general area previously had encountered showings of oil in the same zone or had yielded oil on drill-stem tests. The Connell No. 33 was completed, April 28, 1948, at a plugged-back depth of 8,867 feet, after having found salt water in Ellenburger dolomite at the total depth of 8,983 feet. The casing was perforated between the depths of 8,830 and 8,855 feet, opposite the porous Simpson sand, and on the Railroad Commission of Texas potential test, May 6, 1948, the well produced 589.26 barrels of 44.2° gravity oil in 24 hours, flowing through a $\frac{1}{4}$ -inch choke, with a gas-oil ratio of 862 to 1. The flowing pressures were 930 pounds per square inch on the casing and 830 psi on the tubing.

In the discovery well the top of the Simpson group, overlain by 200 feet of Montoya limestone (Upper Ordovician), was encountered at 8,000 feet (subsea datum, -5,169), and the top of the underlying Ellenburger dolomite, at 8,915 feet (subsea datum, -6,084), indicating a total thickness for the Simpson of 915 feet. Three well defined sand zones were shown by the Schlumberger electrical log to be present in the Simpson section; the upper two sands correspond with the well known McKee and Waddell producing sands of Pecos and Crane counties and elsewhere on the platform but were non-productive in this test, while the lowest sand is the new reservoir (Fig. 1). On discovery of oil in this sand, the name "Oil Creek sand" was immediately accepted in general usage, since the sand was believed to occur in a section equivalent to the Oil Creek formation of the Simpson of Oklahoma,³ which age assignment is probably essentially correct.

¹ Manuscript received, November 15, 1948. Published by permission of The Texas Company.

² Geologist, The Texas Company. The writer wishes to thank The Texas Company for permission to publish this geological note. He is especially grateful to E. Russell Lloyd and to R. V. Hollingsworth who critically read the manuscript and offered valuable suggestions.

³ The Oil Creek formation of Oklahoma "derives its name from Oil Creek which crosses it in Sec. 17, T. 3 S., R. 4 E., about 14 miles south of Sulphur." C. E. Decker and C. A. Merritt, "The Stratigraphy and Physical Characteristics of the Simpson Group," *Oklahoma Geol. Survey Bull.* 55 (1931), p. 18.

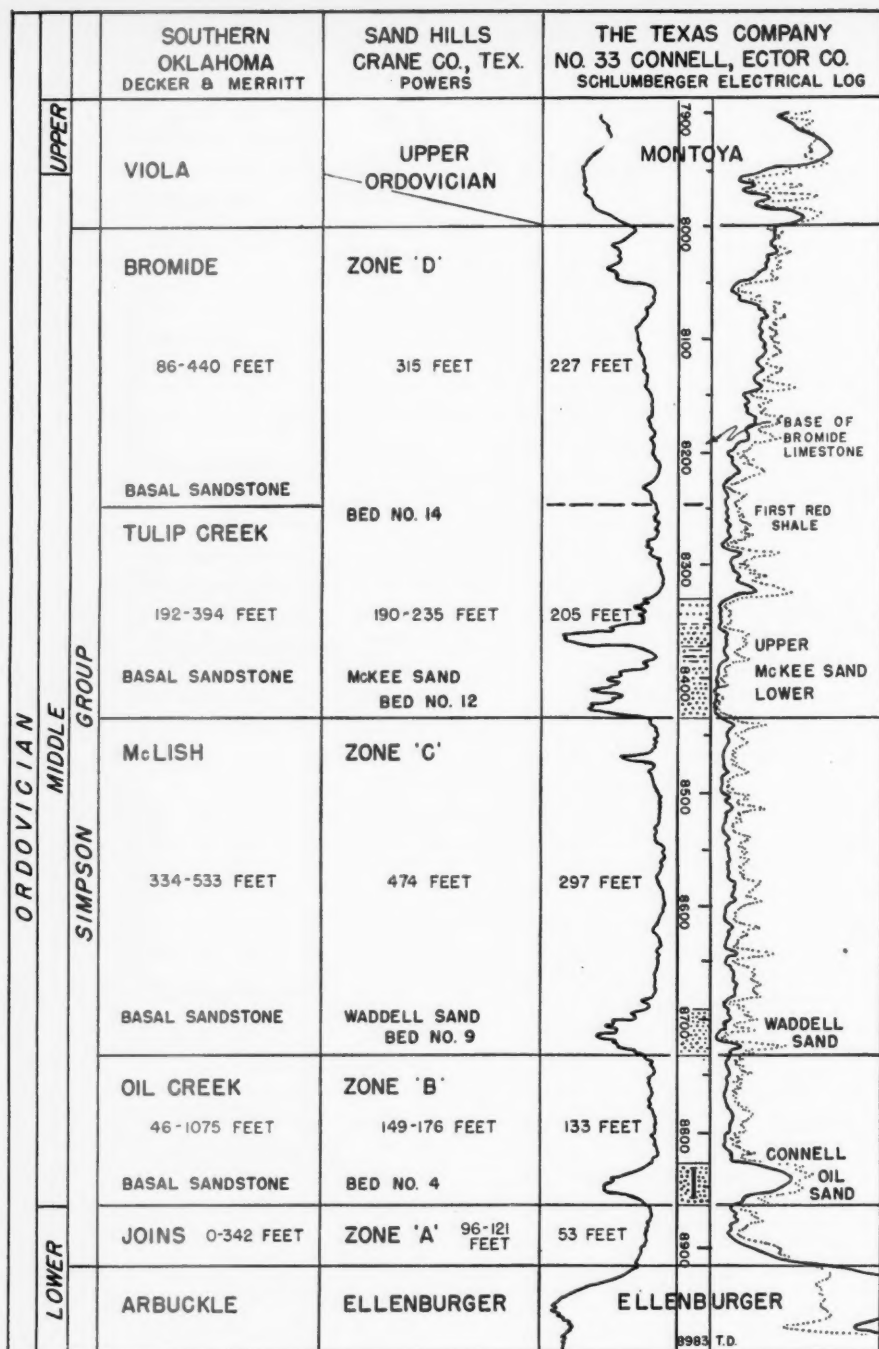


FIG. 1.—Tentative correlation of Simpson group, of southern Oklahoma, Sand Hills area, Crane County, Texas, and Jordan area, Ector County, Texas.

It is not good nomenclatural practice, however, to recognize a geologic formation and a contained member, or smaller rock unit, by the same name; furthermore, the adoption of the Oklahoma formation names for the divisions of the West Texas subsurface Simpson has not been established in the geologic literature, although these names are now in common use by West Texas geologists. The name "Connell sand" was proposed by The Texas Company for the new producing sand in the Connell well No. 33 at a hearing before the Railroad Commission of Texas, July 7, 1948, for a discovery allowable. A new field designation "Jordan Connell Sand field" was granted July 12, 1948, by the Commission. The name "Connell sand" quickly supplanted the undesirable name "Oil Creek" for the new reservoir. The two other important sands of the Simpson, the McKee and Waddell sands, were previously named for their respective discovery wells; these are, the Magnolia Petroleum Company's J. S. McKee No. 1-A in Sec. 24, Blk. 9, H & G N Survey, Pecos County, Texas, and the Gulf Oil Corporation's W. N. Waddell *et al.* No. 1 in Sec. 4, Blk. B-27, Public School Land Survey, Crane County, Texas.⁴

The critical parts of the Schlumberger electrical log and the sample log on The Texas Company's W. E. Connell No. 33 are submitted as type logs⁵ (Fig. 2), showing the immediate stratigraphic relationships of the Connell sand, and these logs are supplemented by the electric log on The Texas Company's Ida McDonald No. 14, which is about $\frac{3}{4}$ mile northwest of the "type locality" in Sec. 27, Blk. B-16, Public School Land Survey. The Connell sand at the "type locality" is 40 feet thick; the top was encountered at the depth of 8,822 feet, 822 feet below the top of the Simpson and base of the overlying Montoya limestone, 93 feet below the base of the Waddell sand, and 93 feet above the Ellenburger dolomite. No cores were taken through the sand in the discovery well, but a Schlumberger side-wall core from The Texas Company's Ida McDonald No. 14 at 8,595 feet shows the sand to be light tan, medium- to coarse-grained, and fairly loosely cemented with slightly calcareous material. The sand is saturated with oil when fresh and has excellent porosity and permeability, although actual porosity and permeability tests on the small core did not furnish dependable results.

As matters now stand, the McKee, Waddell, and Connell sands would be "members" of the Simpson group. In order to rectify this nomenclatural inconsistency, it is necessary to discuss briefly the regional correlations of the Simpson.

In Oklahoma, Decker and Merritt⁶ recognized five formations of the Simpson

⁴ Taylor Cole, C. D. Cordry, and H. A. Hemphill, "McKee and Waddell Sands, Simpson Group-West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 2 (February, 1942), pp. 279-82, Fig. 1.

⁵ See Note 4, entitled "Naming of Subsurface Stratigraphic Units," prepared for the American Commission on Stratigraphic Nomenclature by W. V. Jones and R. C. Moore, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 32, No. 3 (March, 1948), pp. 369-70.

Note.—The samples from the Connell No. 33 were poor through the Simpson section. Therefore, the lithologic interpretations shown by the sample log in Figure 2 are based partly on samples and characteristics of the Schlumberger log, and, in addition, the cores from the Ida McDonald No. 14 were used for interpretation of the Joins part of the section.

⁶ C. E. Decker and C. A. Merritt, *op. cit.*, pp. 11, 12.

THE TEXAS CO.
NO. 33 W.E. CONNELL
ELEVATION 2831'

THE TEXAS CO
NO. 14 IDA McDONALD
ELEVATION 2842'

SAMPLE LOG ELECTRICAL LOG

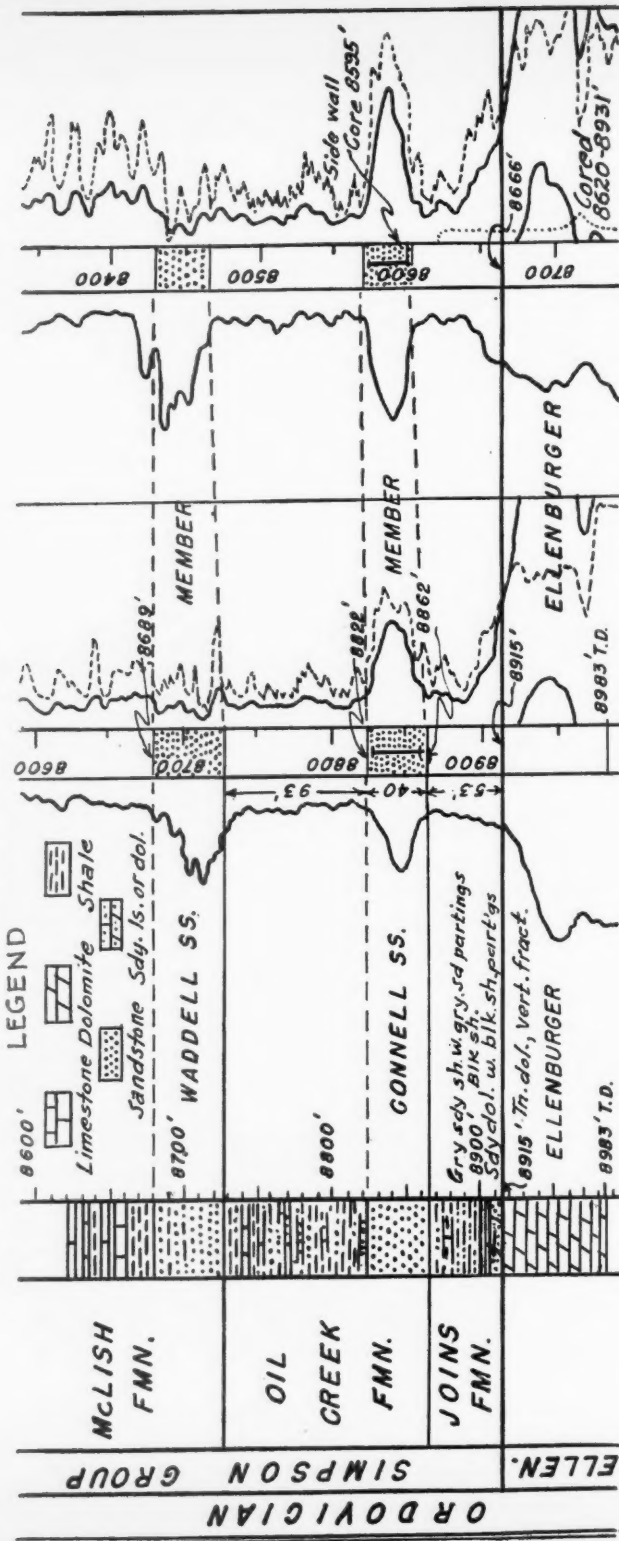


FIG. 2.—Parts of sample log and Schlumberger electrical log of The Texas Company's W. E. Connell No. 33 and electrical log on The Texas Company's Ida McDonald No. 14, Ector County, Texas, showing stratigraphic relationships of Connell sand. Logs on No. 33 Connell illustrate "type section."

group, namely, from bottom to top, Joins, Oil Creek, McLish, Tulip Creek, and Bromide. E. H. Powers,⁷ in his paper on the Sand Hills area in Crane County, states that faunal evidence indicates that a fairly complete equivalent of the Simpson group of Oklahoma is present in the West Texas (Pecos County) Magnolia McKee test, in which the Simpson attains a thickness of 1,327 feet. Powers did not accept and apply the five-partite division of the Oklahoma surface section to the West Texas Simpson, but for convenience lithologically divided the section into four zones, which he called, from bottom to top, Zone "A," Zone "B," Zone "C," and Zone "D." These four zones can be recognized in the Connell No. 33, with the possible exception of Zone "A" which is here discussed, and regional thinning of the whole group northeastward from Pecos County accounts for the thinner section of 915 feet in the Connell well in southern Ector County. The Connell sand undoubtedly corresponds with Bed 4, Zone "B" of Powers'⁸ section, and on the basis of faunal evidence Zone "B" can be shown to be equivalent to at least a part of the Oil Creek formation of Oklahoma.

Although usage has now in a sense established formational rank for five recognizable units of the subsurface Simpson of West Texas and the adoption of Oklahoma names for these has become rather general, the proposal to accept the Oklahoma terminology for the subsurface subdivisions has not, in the writer's knowledge, been made in the geologic literature. However, the West Texas Geological Society Pre-Permian Study Group issued a columnar section of pre-Permian formations of the Central Basin platform,⁹ in which the Oklahoma subdivisions of the Simpson group were used, but no further attempt was made to introduce this nomenclature in the literature. Since, on paleontological grounds, all of the formational units of the Oklahoma type Simpson can be shown to be represented in the subsurface of West Texas, and since the group in West Texas can also be subdivided on lithologic grounds, not in conflict with the former, it is proposed that the Oklahoma formational names be applied to the recognized subdivisions of the subsurface Simpson with the McKee, Waddell, and Connell sandstones as basal members of certain formations as follows.

- Simpson group
 - Bromide formation
 - Tulip Creek formation (top of red shale)
 - McKee sandstone member (basal sand)
 - McLish formation
 - Waddell sandstone member (basal sand)
 - Oil Creek formation
 - Connell sandstone member (basal sand)
 - Joins formation
- Ellenburger group

⁷ E. H. Powers, "Sand Hills Area, Crane County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), p. 123.

⁸ E. H. Powers, *ibid.*, pp. 124, 125.

⁹ Barton, Jackson and others, "Columnar Section of Pre-Permian Rocks of Central Basin Platform, West Texas and Southeastern New Mexico," compiled by Pre-Permian Study Group, West Texas Geol. Soc. (1946).

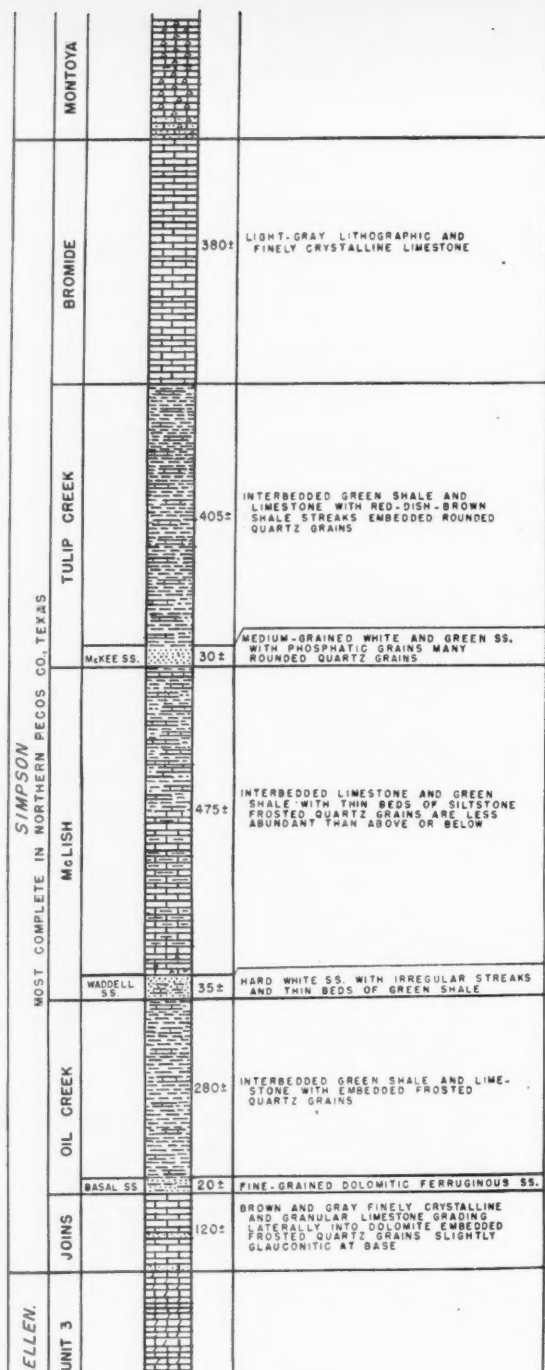


FIG. 3.—Part of "Columnar Section of Pre-Permian Rocks of Central Basin Platform, West Texas and Southeastern New Mexico," prepared by Pre-Permian Study Group of West Texas Geological Society, showing lithology of Simpson group.

The West Texas Geological Society's columnar section furnishes an excellent generalized section of the subsurface Simpson group (Fig. 3).

It is outside the scope of this paper to discuss the paleontology and details of the stratigraphy of the Simpson of West Texas. However, Figure 1 presents a tentative correlation of the subsurface Simpson sections of the Sand Hills area, Crane County, and Jordan area, Ector County, Texas, with the standard Simpson section of southern Oklahoma.

The boundaries of the divisions of the Simpson in Texas can not be said categorically to conform with those of the Oklahoma outcrop formations exactly as shown in Figure 1, but a comparison of the ostracods and other diagnostic fossils present in the formations of the two regions do show these correlations to be entirely possible and essentially correct. Furthermore, the presence of a basal sandstone at the bottom of each of the upper four divisions of the Simpson in Oklahoma¹⁰ lends support to placing the boundaries of the Texas subsurface divisions at the base of the well developed McKee, Waddell, and Connell sands, particularly since in other respects the sedimentation in the two widely separated regions are similar. Zone "D" of Powers' Texas section probably includes both Bromide and Tulip Creek equivalents, and the sand corresponding with the basal sandstone of the Bromide is absent or poorly developed in the Texas subsurface. Some workers¹¹ recognize the top of the "Tulip Creek" of the Texas Simpson at the first appearance of a reddish shale which in the McKee test is Bed 14 of Powers' section (Fig. 1), while the West Texas Geological Society's Study Group recognizes the top at the first appearance of relatively thick shale beds beneath the well developed Bromide limestone section. This latter recognition places the top slightly higher in the section.

It was not determined on paleontological grounds whether all or part of the beds between the Connell sand and the Ellenburger in the Connell No. 33 were Joins in age, and equal to Zone "A" of Powers, but the lithologic character of cores from The Texas Company's Ida McDonald No. 14, at the Ellenburger-Simpson contact, between 8,632 and 8,666 feet strongly suggests the presence of Joins equivalents, and the top of the formation was arbitrarily placed at the base of the Connell sand as shown in Figures 1 and 2. Rocks of Joins age definitely are known elsewhere in the West Texas Simpson; therefore, they could reasonably be expected in the Jordan area. The most conclusive evidence of the presence in West Texas of rocks of this age was furnished by a core from the Stanolind's J. S. Todd No. 1, Sec. 67, Blk. UV, G C & S F Survey, Crockett County, between 7,236 and 7,240 feet, which yielded an almost complete and well preserved specimen of a graptolite. The graptolite was sent to Rudolf Ruedemann of the New York State Museum for identification, and he stated:¹²

¹⁰ C. E. Decker and C. A. Merritt. *op. cit.*, p. 11.

¹¹ M. E. Upson, personal communication.

¹² Letter, April 5, 1939.

The graptolite leaves no doubt that it is a very large specimen of *Didymograptus bifidus*. Both *D. arctus* and *D. bifidus* are known from various outcrops of the Joins formation in Oklahoma and Arkansas, and you are probably right in considering the rock in the well at 7,240 feet also as Joins formation of the Simpson group.

Fragments of graptolites which may represent *D. bifidus* also were found in cuttings from the Magnolia's McKee No. 1-A well in Pecos County between 6,000 and 6,010 feet.¹³

In the Jordan Connell area, as in the Sand Hills area of Crane County,¹⁴ there is no evidence of an erosional unconformity between the basal Simpson and the Ellenburger. The cores through the contact in the Ida McDonald No. 14 test show only a sharp lithologic break from the black shale and sandy dolomite with black shale partings, of probable Joins age, to tan gray dolomite showing vertical fracturing, of Ellenburger age, but no basal sandstone or detrital material was present at the contact.

The cuttings, cores, and logs of the Connell No. 33 and the Ida McDonald No. 14 are on file in The Texas Company's offices in Midland, Texas.

¹³ The occurrence of *Didymograptus bifidus* (Hall) in the Joins formation of West Texas is the basis for placing it in the Lower Ordovician as shown in Figure 1. This graptolite was originally described from Point Levis (Quebec) but Ruedemann, in "Graptolites of New York," Part I, *New York State Museum Memoir 7* (1904), p. 690, records it from graptolite beds 3 to 5 of the Deepkill section (Beekmantown) of New York. Beekmantown is considered Lower Ordovician in age. Most West Texas subsurface workers, including the Pre-Permian Study Group of the West Texas Geological Society, place the whole Simpson group in the Middle Ordovician.

¹⁴ E. H. Powers, *ibid.*, p. 122.

EXPLORATION FOR OIL IN JAPAN¹

LLOYD W. STEPHENSON²

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Oil exploration in Japan is coordinated and promoted by the Petroleum Resources Development Promotion Council (formerly Petroleum Exploration Advancement Committee), which advises the Mining Bureau of the Ministry of International Trade and Industry on all matters concerning oil exploration in Japan.

A review of the work of the PRDRC shows that, apart from its routine operations of planning geological and geophysical survey projects and considering proposals for location of exploration test wells connected with the short-range projects which have already resulted in significant increases in the known reserves, the Council has compiled a large amount of pertinent data directed toward the long-range objective of clarifying the present state of geologic knowledge of

¹ Information Bulletin No. 18. Released from Public Information Office, General Headquarters, Far East Command, APO 500, c/o Postmaster, San Francisco, California. Received, October 21, 1949. This is an abstract of a report prepared by the writer, for the Supreme Commander for the Allied Powers.

² Visiting expert consultant, on tour of duty with the Natural Resources Section. Geologist, United States Geological Survey, Washington, D. C.

the producing areas and of potential petroliferous areas in Japan, so that future exploration can be planned on a sound basis.

These data are at present being assembled, under the guidance of the Natural Resources Section, into a comprehensive report on the petroleum geology of Japan, which will make possible a more accurate assessment of potentialities than was previously possible. The Council's work has already provided a significant contribution to the Japanese economy, and its methods of procedure, built up under the guidance of the Natural Resources Section, are highly commendable. Alan M. Bateman, visiting expert consultant, in his review of geological investigation in relation to Japanese mineral resources, stated that the Council is "the finest example of coordinated cooperative geological work in Japan."

The data relating to the occurrence and production of petroleum in the oil fields of Honshu show that commercial accumulations are developed in sandstone and tuffaceous sand facies of late Miocene and Pliocene age, and that intervening mudstones are the probable source rocks which yielded the oil to the sand reservoirs. The oil is accumulated in several types of structural traps and some promising structures are known which have not been tested by drilling. Similar structures will doubtless be discovered as a result of the exploration now in progress. The oil possibilities in northwestern Honshu are believed to be limited to the upper Miocene and Pliocene rocks, because the basement on which they rest is physically unfavorable for the occurrence of petroleum.

Prospects based on present information are that petroleum will be produced in northwestern Honshu for many years. Also the amount produced annually may be materially increased by the extension of fields and the discovery of new fields. However, the natural limitations seem to preclude any spectacular increase in production in the northwest Honshu area.

To date, petroleum production in Hokkaido has been small; it has been derived from Miocene and Pliocene (Neogene) beds in the Kitami district in the north (six fields), the Ishikari district north of Sapporo (two fields), and the Atsuma district in south central Hokkaido (three fields). The small production from these fields has tended to discourage exploration in these Neogene formations, but the possibilities of additional production from these younger sediments should not be regarded as exhausted.

The main hope of increasing production in Hokkaido now rests on the possibility of commercial quantities of oil in, or derived from, Cretaceous sediments. In contrast to the oil-producing districts of northwestern Honshu, the similar districts of Hokkaido are bordered on the east by a thick series of outcropping mudstones and intervening sandstones of Cretaceous age, and in the north, the stratigraphic relations of these beds, as seen in the outcrop, suggest that they extend westward in the subsurface beneath the Neogene formations from which oil is now obtained in the Kitami district. A reconnaissance examination across three selected sections in the northern area gave the impression that in the belt of outcrop the Cretaceous beds have been subjected to severe orogenic move-

ments that have resulted in strong induration, steep dips, and a rather low degree of porosity in the sandstones (reservoir rocks). The prospect of production does not seem very promising in this Cretaceous area. However, oil seepages in these Cretaceous rocks suggest that the mudstones are possible source rocks.

The apparent unfavorable aspect of the Cretaceous rocks in the belt of outcrop does not necessarily apply to the rocks of that age in their westward extension beneath the Neogene sediments. At present, the physical condition of the sediments here is unknown and can be ascertained only by test drilling. However, there is a definite possibility that the folding there is less severe and that the degree of porosity of the sandstones is higher. Should this be found to be the condition, the prospects for petroleum accumulations in commercial amounts seem to be favorable. Judged from the greater size of the structures in Hokkaido as compared with those of Honshu, if they are productive, the accumulations may be more significant than those of Honshu.

The Cretaceous and Paleogene formations in the southern part of the belt of outcrop in Hokkaido have been subjected to even more severe orogeny than those in the north, and the prospect for obtaining petroleum from these beds seems unfavorable, except in their possible buried extensions on the west or southwest beneath Neogene sediments.

As a result of the writer's investigations the following recommendations are offered:

1. The activities of the Petroleum Resources Development Promotion Council should be continued until its objectives are fully realized.
2. More insistence should be placed on uniform presentation of data for the report on the petroleum geology of Japan now being prepared by the Council.
3. More attention should be paid to petrographic study and determination of porosity in potential reservoir rocks in regions now being explored, and in particular, in the Cretaceous areas of Hokkaido.
4. To aid stratigraphic correlation, more extensive paleontological research is needed to establish fossil zones in the Cretaceous and Tertiary rocks of the producing and potentially petroliferous area. Particular attention should be given to the zonation of the Cretaceous rocks of Hokkaido.
5. Geophysical survey for detection of concealed structures in alluvial areas should be continued and new geophysical methods should be introduced as additional aids to exploration.
6. Academic institutions should be encouraged to continue their surveys and investigations bearing on oil exploration, and to coordinate their results with those of other agencies.
7. Special attention should be given to the potentialities of petroleum production in the Kwantō geosynclinal basin.
8. The comprehensive account of the petroleum geology of Japan, now in preparation by the Council, should be completed as soon as possible and made available to the public to encourage greater enterprise in the petroleum-producing industry.

DISCUSSION

SAMPLING AND EXAMINATION OF WELL CUTTINGS¹

MARCUS I. GOLDMAN²
Washington, D. C.

There is one modification the writer would recommend for the graphic log (Fig. 7, p. 82) in John M. Hills' useful paper on "Sampling and Examination of Well Cuttings," in the January, 1949, *Bulletin*. Instead of logging lithologic types—sandy shale, sandy dolomite, *et cetera*—he would recommend logging mineralogic constituents—sand, clay, lime, dolomite, anhydrite, *et cetera*. This was the method used in the writer's "Lithologic Sub-surface Correlation in the 'Bend Series' of North-Central Texas," *U. S. Geol. Survey Prof. Paper 129* (1921), pp. 1-22. As explained more fully there, this has the advantage that it makes more provision for readily recognizing lateral variations in beds—of a sandy shale to a sandstone, an argillaceous limestone to a shale, and so on. It also reduces the number of constituents to be shown in the graphic log and thus makes the log easier to evaluate at a glance.

It is interesting to learn that Hills found (pp. 84-85), as did the writer, that estimates of proportions of constituents by eye can be made with sufficient accuracy. With experience, acid tests, and an occasional thin section, estimates of mineral constituents can be made as readily as estimates of lithologic constituents.

¹ Manuscript received, July 30, 1949.

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PIONEERS IN GEOLOGY¹

WALLACE E. PRATT²
Carlsbad, New Mexico

Some of the pages of Geological Notes have recently been devoted to the compilation of a geologic "Hall of Fame."

In the May *Bulletin*, "Pioneers in Geology," page 720, Professor Burt, of the Agricultural and Mechanical College of Texas, records the names of the twenty-four men most frequently selected by graduate students over a period of years, as having "contributed most to the advancement of geologic science" during the two centuries between 1725 and 1925. In the August *Bulletin*, "Pioneer Geologists," page 1430, Professor Woodford, of Pomona College, comments on Professor Burt's list and suggests the substitution of other outstanding pioneers for eight of the men most frequently selected by the Texas students.

Altogether, in the compilation of these two lists, the names of more than forty pioneer geologists are suggested as worthy to be included. It is surprising that nowhere is Edward Suess mentioned.

Has the stature of the author of *Das Antlitz der Erde* so diminished in the present generation?

¹ Manuscript received, October 12, 1949.

² Box 209, Carlsbad.

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

UR- UND NEOZEANE, BY HANS STILLE

REVIEW BY PARKER D. TRASK¹

San Francisco, California

"Ur- und Neozoeane" (Ancient and Modern Oceans), by Hans Stille. *Abhandlungen der Deutschen Akademie der Wissenschaften zu Berlin, Math.-Naturw. Klasse, Jahrgang 1945/46, Nr. 6 (1948)*, pp. 1-68; 2 pls., 4 figs.

Professor Stille's essay on the structural relationships between oceans and adjacent landmasses is very provocative. In this article, Stille attempts to analyze a vast number of geological and geographic data from all parts of the world and to synthesize them into a coherent hypothesis explaining the structural framework of the oceans.

Stille postulates two kinds of oceans: *ancient* (Urozeane) and *modern* (Neozoeane). *Ancient* and *modern* are not exact equivalents of *Ur*, which means *pristine* and of *Neu* which means *new*, but they are convenient English words to use. The ancient oceans are defined as those oceans which are surrounded by folded and faulted margins in which the tectonic lines are essentially parallel with the borders of the ocean. The typical ancient ocean basin acts as the hinterland (Rückland) for the deformed areas on the margins. The underlying rocks consist essentially of basic rocks (sima) and the basins contain no remnants of foundered landmasses. If islands are present within the basin, they consist of basaltic rocks. The ancient oceans are older than Cambrian and probably are early Algonkian or Archean. Once formed, they persist forever, in contrast to continental landmasses which may increase or decrease in size by the respective destruction or formation of geosynclines.

Modern oceans are of more recent age, Cambrian or later, and in part are formed from sunken landmasses. They are associated with geosynclines (Orthosynklinalen), and the structural lines of adjacent landmasses intersect the margins of the ocean obliquely. The ocean basin acts as a foreland (Vorland). The rocks in the basin are intermediate in character and are postulated to contain appreciable quantities of sial, which may or may not have been derived from sinking landmasses.

None of the oceans or deep-sea areas of the earth fit either category of ocean in all respects. Stille states in his preface that after having postulated the existence of these two types of ocean, he wishes to examine the world in order to classify the present water areas into one of these two groups.

He contemplates five ancient oceans: 1, Urpazifik; 2, Urarctik; 3, Urskandik (Ancient Scandinavian); 4, Northern Uratlantik; and 5, Southern Uratlantik. These ancient oceans in part were formerly bordered by land areas, which subsequently have foundered.

The Ancient Pacific occupies the present Pacific Ocean except for the area west of the "andesitic line," in the general location of the Philippine Sea, which he considers as a modern ocean because it seemingly contains remnants of foundered land areas or admixtures of sial. The land areas bordering the Pacific Ocean consist of orogenic belts having structural lines essentially parallel with the coast line. The principal exception is the ancient Antillean orogeny in the Caribbean area, for which the Pacific seemingly acted as a foreland.

¹ California State Division of San Francisco Bay Toll Crossings. Review received, October 4, 1949.

The Ancient Arctic ocean has approximately the same boundaries as the present Arctic Ocean. On the whole, it is bordered by folded land areas having tectonic lines parallel with the coast line, except for the Ural and Okhotsk orogenic belts which intersect the shoreline obliquely.

The Ancient Scandinavian ocean, lying between Greenland, Spitzbergen, Norway, and Iceland, is rimmed by folds parallel with the former shoreline. Though small in size, it is the most typical ancient ocean.

The present Atlantic Ocean has been formed from two ancient oceans,—the Northern Uratlantik and the Southern Uratlantik, by the foundering of Gondwanaland. In general these ancient oceans are bordered by orogenic lines parallel with the edge of the ocean. The agreement is less perfect than for the other ancient oceans. In the North Atlantic the Tethys and modern Antillean orogenies do not conform with the pattern of rim folds; and in the South Atlantic the Antarctic tectonic belt at the south end of South America, likewise is out of harmony with the general pattern. Stille regards such orogenies as *xenogenic*, as they represent elements alien to the series of events associated with the genesis or characteristics of the ancient oceans. For the large part, they are much more recent in age, and they more closely resemble phenomena associated with geosynclines and modern oceans (Neuozeane).

Stille in this article is primarily interested in recognizing the existence of ancient oceans. He discusses modern oceans in much less detail. The best example of a modern ocean is the Indian Ocean, which contains remnants of foundered landmasses within its basin and acts in many places as a foreland for orogenic deformation in adjoining land areas. Furthermore the structural lines in several of these orogenies are not parallel with the borders of the ocean.

Other modern oceans are the Philippine Sea, the Caribbean Sea, and the Mediterranean Sea. The last, because of its relatively shallow depth, perhaps should not be considered a *Neuozean*.

A reviewer should endeavor to appraise the merits of the article he reviews. However, because of the many kindnesses of Professor Stille when the reviewer was a student in his laboratory in Göttingen more than 25 years ago, it is preferred not to attempt to comment critically on this paper for fear of offending him by possible misinterpretation of his argument. After all, Stille's paper is largely theoretical. He has tried to make a plausible story out of a vast number of individual data. His thesis could be substantiated or disproved, only after an equally exhaustive analysis of data. Furthermore, no matter whether or not Stille has proved his point, the more fundamental problem of the causes of the original distribution of silica and iron in the primordial earth and the subsequent readjustments of these substances, if they do exist, has not been considered in this paper. Nevertheless, no matter how one looks at this problem, Professor Stille has given us a very stimulating paper.

PRE-CHATTANOOGA STRATIGRAPHY IN CENTRAL TENNESSEE,
BY CHARLES W. WILSON, JR.

REVIEW BY T. E. WEIRICH¹ AND JOHN H. WEBB¹
Bartlesville, Oklahoma

"Pre-Chattanooga Stratigraphy in Central Tennessee," by Charles W. Wilson, Jr. *Tennessee Div. Geol. Bull.* 56. Nashville (1949). xviii, 407 pp., 89 figs., 28 pls. Price, \$2.65.

This new bulletin treats of the Ordovician, Silurian, and Devonian rocks exposed in

¹ Phillips Petroleum Company. Review received, October 21, 1949.

the Central Basin, the Sequatchie Valley, and the Western Valley of the Tennessee River. For almost a century these limestones and shales have drawn the attention of geologists. Relatively thin, reasonably flat, and abundantly fossiliferous, they have been the subject of numerous investigations. Published material dates back to 1851, when Safford's pioneer work appeared.

Wilson has completed reconnaissance mapping of all pre-Chattanooga formations exposed in the Central Basin and the Western Valley. *Bulletin 56* is the result of this work which has been in progress since 1937. Previous work in the area has not been slighted; type localities and classic exposures, which form a most essential framework for the bulletin have been revisited and restudied. Wilson presents the various features of each formation with respect to the entire middle Tennessee region, eliminating detailed "county-by-county" comparisons. His stated purpose is to achieve a unified picture of the pre-Chattanooga formations in central Tennessee; *Bulletin 56* does the job!

Generous use of illustrative material adds greatly to the bulletin's effectiveness. More than 300 measured sections are plotted to scale and combined into 30 stratigraphic cross sections, each presenting either a single formation or a related group. Ten index maps show the location of these sections. Thirty-four isopach maps present the distribution and thickness of formations and their various facies. Five areal distribution maps are used where isopach maps are impractical. Eight diagrams give previous and present interpretations of stratigraphic relationships. Twenty-eight plates picture the more important Ordovician and Silurian fossils. The plates are grouped at the back of the bulletin; other illustrations are conveniently located near pertinent text. A structural map of central Tennessee, contoured on the base of the Chattanooga shale, and a sub-Chattanooga geologic map accompany the bulletin. Both maps are on a 1/500,000 scale. There are no pictures of general scenery or outcrops; each illustration is a functional part of the bulletin.

Slightly more than half the bulletin (215 pages) is devoted to the Ordovician system; these rocks crop out over broad areas in the Central Basin. Previous workers recognized facies variation in some Ordovician formations. Wilson has worked out the vertical and lateral distribution of facies within each variable formation, and demonstrates the contemporaneity of contrasting lithologies. The Bigby and Cannon limestones are shown to be contemporaneous facies; this reaffirms the early views of Ulrich, and corrects Bassler's interpretation of the Bigby as a separate formation. Several other additions to Ordovician knowledge are made. The Catheys formation is extended to the east side of the Central Basin, including beds mapped by Bassler as upper Cannon. Limestones of Eden age are recognized in the Central Basin. The first complete study of Richmond strata in central Tennessee is presented. Throughout this part of the bulletin, established nomenclature is followed as closely as possible; only one new formation name is formally introduced. Facies are generally given descriptive rather than geographic names, in keeping with their erratic lenticular distribution. By presenting much detail, clarifying both local and regional stratigraphy, and avoiding a clutter of new names, Wilson gives the Ordovician masterful treatment.

The main out crops of Silurian rocks occur in and near the Western Valley and along the west margin of the Central Basin. Discussion of this system is contained in 40 pages. Added knowledge of areal distribution is the main feature of this section; no important changes in the stratigraphic sequence are made. At several key exposures Wilson disagrees with the correlations of earlier workers. He ascribes these differences to their reliance on fossil zones and neglect of lithologic sequence. In contrast to the very thorough presentation of the Ordovician system, the Silurian treatment seems rather brief; it suffers by comparison.

Devonian rocks crop out at several localities in the Western Valley and along the northwest side of the Central Basin. Most of the 40-page Devonian discussion treats of

the Western Valley area. The main feature of this part of the bulletin is Wilson's interpretation of the Lower Devonian. His use of the contemporaneous facies concept leads to extensive revision of the sequence established by Dunbar in 1919, as the following comparison shows.

<i>Dunbar, 1919</i>	<i>Wilson, 1949</i>
Harriman chert	Harriman formation
<i>Break</i>	<i>Unconformity</i>
Quall limestone	Flat Gap limestone
<i>Break</i>	<i>Unconformity</i>
Decaturville chert	Ross formation
<i>Break</i>	(Includes Birdsong shale member, Bear
Birdsong shale	Branch facies, Ross limestone member,
<i>Break</i>	Rockhouse shale member, Rockhouse
Olive Hill formation	limestone member, Decaturville zone
Flat Gap limestone	and Bryozoan zone.)
Bear Branch-Pyburn limestone	
Ross limestone	
<i>Break</i>	
Rockhouse shale	

From the small, scattered Lower Devonian outcrops, Wilson has constructed a very plausible interpretation of the stratigraphy. Lack of continuous outcrops will make its definite proof or disproof equally difficult. As a new and thought-provoking approach, the facies interpretation has considerable merit.

The final pages of the bulletin contain a discussion of the larger structural features of central Tennessee and their control of stratigraphy, and a presentation of pre-Chattanooga geologic history.

The reviewers found one spot where Wilson's reasoning is not clear. On page 345, in discussing the Ross formation, Wilson postulates a supply of clastics from the south. The basal part of the formation suggests this, as it is shale in southerly exposures and limestone farther north. The main body of the formation, however, contains a greater concentration of fine clastics in its northern (Birdsong shale) facies, according to the lithologic descriptions given. It is difficult to reconcile a shaly facies on the north with a clastic source on the south.

The quality of illustrations is generally good. There are a few points, however, that merit criticism. Figure 86 (page 305) shows the distribution of some Devonian formations. The ruled patterns used in this figure are too fine-textured to reproduce clearly. The Brassfield isopach map (Fig. 74, page 242) has an obvious contouring error in the western part. Though magnifications of enlargements in the fossil plates are stated, the reader is left to assume the relative size of most of the fossils; some of the pictures are certainly reduced in size. Omission of all Devonian fossils from the plates is not explained.

Minor errors in typography are numerous enough to be annoying. Most of these could have been eliminated by more careful proof-reading.

Bulletin 56 is a major contribution to the geologic knowledge of Tennessee. The errors and omissions noted do not appreciably affect its total worth. Readers will find it both stimulating and authoritative; for work in the pre-Mississippian of the central United States, it is a most valuable reference.

AN INTRODUCTION TO PHYSICAL GEOLOGY, BY WILLIAM J. MILLER

REVIEW BY ROBERT W. WEBB¹

Santa Barbara, California

An Introduction to Physical Geology, with Special Reference to North America, by William J. Miller. 5th ed. (1949). Van Nostrand, Inc., New York. 482 pp.; 397 figs. Price, \$4.50.

The fifth revision of *Introduction to Physical Geology*, by William J. Miller, a text which first appeared in 1924, represents a thorough modernization of this well known book, providing an even better foundation than earlier editions for classes in general physical geology, particularly for the non-technical liberal arts student.

Significant changes include: (1) a more lucid presentation of the introductory phases of geology in understanding the earth within and without in modern life; (2) revision of the chapter on rocks to make the section on sediments more complete; (3) discussion of weathering in its most recent interpretations, comparing present ideas with older theories of mechanical and chemical processes; (3) presentation of modern ideas of velocity-volume-mass transport relations in stream work; and (5) new material on volcanism, with new regional examples. Addition of many new photographs implement the text discussion significantly, with illustrations tied to text that they demonstrate better than in earlier editions. Noteworthy is the excellence of the typography, with modern type and format pleasing to, and easy on, the eye. The photographs are particularly well produced.

A new order of topic headings is offered, with a return to the order of earliest editions for the first section on earth materials. The reviewer would prefer the chapter on "Volcanoes" to follow the discussion of rocks, and the chapter on "Structure of the Earth's Crust," to precede "Diastrophism," but any order in any text will be found unacceptable to some users. However, this text lends itself to assignments out of text order more readily than most, because each chapter is a self-contained unit. An omission which some may regret, is a discussion of location of epicenters in Chapter IV.

The writer believes that this revision makes Miller's *Introduction to Physical Geology* clearly the most teachable book in the field, especially for classes in physical geology for the general student.

¹ Associate professor of geology, University of California, Santa Barbara College. Review received, October 21, 1949.

SUBSURFACE GEOLOGIC METHODS, BY L. W. LEROY
AND HARRY M. CRAINREVIEW BY CARROLL E. DOBBIN¹

Denver, Colorado

"Subsurface Geologic Methods," by L. W. LeRoy and Harry M. Crain, Colorado School of Mines, Golden, Colorado (1949). 826 pp., 12 pls., 437 figs. Price: \$7.00, Fabricoid-bound; \$6.00, paper-bound.

This symposium by two professors in the Colorado School of Mines attests further the aggressive and progressive role being played by that institution in all phases of the mineral industry. Eight of the contributing specialists are from Mines, two are from the United States Bureau of Reclamation, eight are from universities, and twenty-two are from leading corporations either in or closely associated with the oil business. Professor

¹ United States Geological Survey. Review received, October 22, 1949.

LeRoy has drawn liberally on his world-wide experience in geology to write twenty per cent of the symposium, and Professor Crain has utilized his excellent knowledge of English and editing to make it orderly, clear, concise and scholarly—a symposium that yields much pertinent information on scattered and even unavailable subsurface geologic techniques and that is invaluable to all teachers, students, and practitioners of geology and petroleum engineering.

Stating that the discovery of most of the world's future oil fields undoubtedly will be attributed to subsurface geologic studies, Professor LeRoy outlines in Chapter 1, Introduction, the training, duties, and techniques of a subsurface geologist, and in Chapter 2, Stratigraphic, Structural, and Correlation Considerations, he outlines the basic stratigraphic and structural principles used in the accurate evaluation of sedimentary units, with emphasis on the facies concept and problems of accurate stratigraphic correlation.

Chapter 3, Subsurface Laboratory Methods, has sections on micropaleontologic, screen, settling, stain, and shape analysis, by Professor LeRoy, sections on calcareous algae, detrital mineralogy, and insoluble residues, and eight other sections on subsurface analytical methods. Besides describing and illustrating the latest laboratory techniques in analysis, the authors of this chapter discuss, among other things, the many and varied duties of the petroleum geologist and engineer, the constant refinement of subsurface geologic methods, the increasing importance of radioactive and drill-time logging, the interpretation of subsurface samples in terms of the sources, conditions of transportation, deposition, and post-depositional changes of sediments, and the precise identification and correlation of minerals by X-ray diffraction methods.

In Chapter 4, Subsurface Logging Methods, thirteen methods of well logging are described and profusely illustrated by fourteen authors, the topics ranging from the interpretation of a drillers' log to the most refined techniques in logging. New methods of logging dry holes and of logging through oil-base mud, contaminating well fluids, and steel casing are some of the techniques described.

Chapter 5, Miscellaneous Subsurface Methods, has ten chapters by twelve authors that describe techniques used in oil-well surveying, directional drilling, coring, and in determining the porosity of oil sands.

In Chapter 6, Subsurface Graphic Representations, Professor LeRoy devotes thirty-four pages to the description and illustration of all types of subsurface graphic representations, showing how carefully selected and prepared illustrations lessen the need for long texts, to the interest and profit of the reader. Colored plates of well-log symbols, full-page cross sections, and block diagrams of oil fields feature this excellent chapter.

Chapter 7, Subsurface Maps and Illustrations, by Julian Low, describes and depicts fully and beautifully in fifty-six pages the best methods of drawing structure contours, of preparing isopach, paleogeologic, facies, percentage, and isolith maps, and of constructing cross sections, block diagrams, peg models, and other geologic illustrations.

In Chapter 8, Reports on Subsurface Geology, Professor Crain gives excellent general counsel on a most difficult task, namely, the writing of a geologic report. Arenaceous means sandy and argillaceous means clayey!

In Chapter 9, Subsurface Methods as Applied in Geophysics, Harrison E. Stommel describes in seventy-five pages the methods, instruments, and results of geophysical exploration. His first sentence states that geophysics is the foremost exploration technique available to the oil industry and his last one states that future oil fields will be found through the combined efforts of the geologist, paleontologist, and geophysicist working together in a spirit of cooperation.

In Chapter 10, Subsurface Methods as Applied in Mining Geology, Professor Kuhn states that an ore deposit has been termed an "accident in geology" and describes in twenty-two pages the various field and laboratory guides used in locating, developing, and

evaluating such a deposit, including the geophysical methods newly accepted by mining companies.

In Chapter 11, *Geologic Techniques in Civil Engineering*, George L. Robb describes in thirty pages the application of geology to civil engineering, that is, how geologists interpret geology in terms intelligible and useful to an engineer.

The final chapter in the symposium lists sources of subsurface information, such as well-sample libraries, paleontological laboratories, and well-log services.

RECENT PUBLICATIONS

ALBERTA

*"Preliminary Map, Cardston, Alberta," by E. P. Williams. *Geol. Survey Canada Paper 49-3* (Ottawa, 1949). Sheet 43×49 inches, approx. Scale: 1 inch equals $\frac{1}{4}$ mile. Geological map, with brief descriptive notes, 2 cross sections, and generalized columnar section. Shows Upper Cretaceous.

ASIA

*"The Boundary between the Pliocene and the Pleistocene in Eastern Asia," by Ting Ying H. Ma. *Acta Geologica Taiwanica*, Vol. II, No. 2 (December, 1948), pp. 77-84; 2 tables. First Series of Science Reports of the National Taiwan University, Taipei, Taiwan, China. In English.

CHINA

*"An Outline and Some Problems of the Stratigraphy of Taiwan," by Ichiro Haya-saka, Ch'ao Ch'i Lin, and Tsang Po Yen. *Acta Geologica Taiwanica*, Vol. 2, No. 1 (July, 1948), pp. 1-29; 1 pl., 6 tables. First Series of Science Reports of the National Taiwan University, Taipei, Taiwan, China. In English.

*"Geomorphology of the Tizard Bank and Reefs, Nan-Sha Island, China," by Ling Chih Kuo. *Ibid.*, pp. 45-54, Fig. 1. In English.

ENGLAND

*"The Trimmingham Chalk," by J. E. Sainty. *Proc. Geologists' Assoc.*, Vol. 60, Pt. 3 (September 29, 1949), pp. 216-18; 1 pl. Benham and Company Limited, High Street, Colchester, England. Price of complete issue, 5/-.

GENERAL

*"Tetraktys, the System of the Categories of Natural Science and Its Application to the Geological Sciences," by L. E. Koch. *Australian Jour. Sci.*, Vol. 11, No. 4 (February 21, 1949). 31 pp., illus. Australasian Medical Publishing Company Limited, Seamer and Arundel Streets, Glebe, New South Wales.

*"Note on a Possible Origin of the Alps," by A. J. Bull. *Proc. Geologists' Assoc.*, Vol. 60, Pt. 3 (September 29, 1949), pp. 161-64. Benham and Company Limited, High Street, Colchester, England. Price of complete issue, 5/-.

Oil and Gas Field Development in the United States, Year Book, 1949 (Review of 1948), Vol. 19. Edited by R. C. Brown and E. J. Raisch. Several hundred pages, with maps, tables, charts. Published by National Oil Scouts and Landmen's Association, Box 1095, Austin, Texas. Price, \$8.50.

Reviews of Petroleum Technology, Vol. 8, 1946 (London, 1949). 445 pp. With this volume the Institute of Petroleum resumes annual publication of its *Reviews of Petroleum*

Technology. This volume contains more than 3,000 references. 6×9 inches. Cloth. The Institute of Petroleum, 26 Portland Place, London W 1, England. Price, 27s. 6d.

MOROCCO

*"Description géologique des gisements pétroliers marocains dans l'ordre historique de leur découverte" (Geological Description of Oil Deposits in Morocco in the Order of Their Discovery), by M. W. Bruderer. *Bull. Assoc. Française Techniciens Pétrole*, No. 77 (October 1, 1949), pp. 3-28; 16 figs. 44 Rue de Rennes, Paris 6, France. In French.

NORTH DAKOTA

*"Glacial Geology of the Oberon Quadrangle," by Paul Patrick Tetrick. *North Dakota Geol. Survey Bull.* 23 (Grand Forks, 1949). 32 pp., 2 pls., 6 figs., 3 tables.

*"The Geology of the Tokio Quadrangle," by David G. Easker. *Ibid.*, *Bull.* 24. 35 pp., 2 pls., 7 figs., 3 tables.

OHIO

"Map of the Berea Sand of Northern Ohio," by Wallace de Witt, Jr. *U. S. Geol. Survey Prelim. Map* 99, Oil and Gas Inves. Ser. (November 3, 1949). Sheet, 41×52 inches. Scale, 1 inch equals 3 miles. For sale by Director, U. S. Geol. Survey, Washington 25, D. C. Price, \$0.50.

*"Geologic Map of Coshocton County, Ohio," by Raymond E. Lamborn. Ohio Geol. Survey, Columbus (1948). Sheet, 22×32 inches, colored. Scale, 1.125 inches equals 1 mile. Price, \$1.00 (plus 3 cents in Ohio).

OREGON

"Geology of the Coastal Area from Cape Kiwanda to Cape Foulweather, Oregon," by Parke D. Snively, Jr., and H. E. Vokes. *U. S. Geol. Survey Prelim. Map* 97, Oil and Gas Inves. Ser. (November, 1949). Sheet, 41×54 inches. For sale by Map Distribution Office, U. S. Geol. Survey, Denver Federal Center, Denver, Colorado. Price, \$0.50.

ROCKY MOUNTAIN REGION

*"Dakota and Muddy Strikes Step Up Denver Basin Play," by Joseph A. Kornfeld. *World Petroleum*, Vol. 20, No. 12 (New York, November, 1949). Pp. 54-57; 96; 6 figs., 5 tables.

*"Oil and Gas Exploration in the Four Corners Area of Arizona, Colorado, New Mexico, and Utah," by J. L. Tatum. *Ibid.*, pp. 69-76; 2 figs., 2 tables.

TENNESSEE

"Stratigraphy and Paleontology of the Brownsport Formation (Silurian) of Western Tennessee," by Thomas W. Amsden. *Yale University Peabody Mus. Nat. Hist. Bull.* 5 (New Haven, 1949). 138 pp., 30 figs., 34 pls. 7×10 inches. Clothbound. Yale University Press, New Haven, Connecticut. Price, \$5.00.

TEXAS

"Geology of the Woodbine Formation of Cooke, Grayson, and Fannin Counties, Texas," by Harlan R. Bergquist. *U. S. Geol. Survey Prelim. Map* 98, Oil and Gas Inves. Ser. (October 31, 1949). 2 sheets, 41×54 inches, each. May be ordered from Map Distribution Office, U. S. Geol. Survey, Denver Federal Center, Denver, Colorado. Price, \$1.00 per set.

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At the recommendation of the A.A.P.G. committee on national responsibility, in order to attain its objective "to plan and advise with the Military Services for the effective application of geology and the efficient functioning of geologists within the Military Services," the executive committee is requesting each applicant for membership to return a statement of his World War II service and his present reserve status, if any, for which purpose a special blank is furnished by Association Headquarters, Box 979, Tulsa 1, Oklahoma.

Transfer from associate to junior.—The executive committee has authorized transfer from associate to junior membership of any person whose original application and attached papers show him to have the minimum requirements for junior membership, without obtaining signatures or statements again from sponsors or references. His signature, address, professional connection (on first page of application), and experience record (on second page) since entering as associate will be sufficient. *Such transfer must be requested by the member involved.* This procedure will result in dues adjustment (from \$10 to \$8) for persons who have been in the Association less than 3 years. To any who overpay 1950 dues before transferring to junior membership, but who do so transfer before the end of 1950, a credit will be given against 1951 dues.

To comply with the new amendments affecting qualifications for membership, new applicants and their sponsors should hereafter use new (1949) application forms and the new (1949) constitution and by-laws. Old forms should be destroyed.

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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 Burton R. Ellison, Robert L. Rist, Ted L. Bear
 Perry Fredrick Sollars, Houston, Tex.
 H. J. McLellan, R. L. Denham, Olin G. Bell
 Joseph Swartz, Evansville, Ind.
 Edward J. Combs, William G. Farrand, R. W. Burns
 William Francis Tanner, Jr., Shawnee, Okla.
 Raymond Sidwell, John P. Brand, W. I. Robinson
 Gerald Homer Tefft, Tyler, Tex.
 R. M. Trowbridge, Ray Youngmeyer, G. C. Clark

Athel G. Unklesbay, Columbia, Mo.

Raymond E. Peck, A. K. Miller, A. C. Trowbridge

Walter Hillman Walne, Jr., Midland, Tex.

John I. Moore, P. D. Moore, F. H. McGuigan

Sam Nail Webb, Jackson, Miss.

B. W. Allen, J. Garst, Frederic F. Mellen

Robert Womack, Jr., New Orleans, La.

H. N. Hickey, H. T. Richardson, Brame Womack

A.A.P.G. PACIFIC SECTION MEETING, LOS ANGELES, NOVEMBER 17-18, 1949. ABSTRACTS

THURSDAY MORNING, 9:30-12:00
AMBASSADOR HOTEL THEATER

Presiding: JOHN E. KILKENNY, Chanslor-Canfield Midway Oil Company, Los Angeles
JOHN H. BEACH, Independent Exploration Company, Bakersfield

9:30 (1) GEOLOGY OF WEST SLOPE OF TEMBLOR RANGE, BETWEEN BITTERWATER CREEK AND SAN DIEGO CREEK

Otto Hackel and Roy W. Turner, Independent Exploration Company, Bakersfield, California.

The stratigraphy of the area studied is similar to that of the west side of the San Joaquin Valley. The Pliocene(?) Paso Robles formation unconformably overlaps Miocene to Cretaceous sediments. Upper to middle Miocene (Monterey group) shales and sands are generally lying on Eocene sandstones or are overturned under them. These Eocene (Canoas) sandstones are found in depositional or fault contact with the Cretaceous core of the Temblor Range. Structurally the region is a strongly deformed wedge of sediments between the San Andreas fault zone on the west and the Cretaceous massif on the east. The apex of this wedge is to the northwest and deformation and overturning of the sediments increase in that direction. Anticlinal or fault closures are not readily discernible in the field. Wells in the area have encountered non-commercial oil sands of lower Miocene age. These oil sands or any other lower Miocene beds are not found in the outcrop; hence, a strong possibility exists of finding stratigraphic accumulations of oil in the regionally high portions of the sedimentary wedge.

9:45 (2) SAN ARDO, A STRATIGRAPHIC ANALYSIS

Thomas A. Baldwin, Jergins Oil Company, San Ardo, Calif.

The San Ardo oil field occurs in a stratigraphic trap at the updip shale edge of the Lombardi sand (upper Miocene). The water table of the field was warped synclinally during early Pleistocene time. The San Ardo field accumulated therefore during the Pliocene. Pliocene sediments of the area are described and termed the "San Ardo group," including three partly interbedded and time equivalent facies, Pancho Rico, Etchegoin, and Paso Robles.

It is shown that the shorelines or buttressed edges of sands occurring in the Salinas area have not been favorable for accumulation. It is suggested that Pleistocene structures should be discounted during future exploration in the Paso Robles-Salinas area.

10:15 (3) GEOLOGY OF RUSSELL RANCH AND SOUTH CUYAMA OIL FIELDS, CUYAMA VALLEY, CALIFORNIA

Rollin Eckis, Richfield Oil Corporation, Los Angeles.

Since the discovery of high-gravity oil in the Cuyama Valley on June 13, 1948, development and exploration have proceeded at a rapid pace. As of October 15, 1949, these operations had resulted in the discovery of two oil fields, and completion of 151 producers, with a restricted daily production of 29,200 barrels. Thirteen development wells and six wildcats were currently drilling.

The two oil fields lie in the western part of the valley. Development to date in the Russell Ranch field covers an area approximately $4\frac{1}{2}$ miles long and $\frac{1}{2}$ mile wide. Trending southeasterly from the top of White Rock Bluff, it straddles the Cuyama River, lying partly in San Luis Obispo County and partly in Santa Barbara County. Production here is from two sand zones, Dibblee, the upper, and Colgrove, the lower. Both are of lower Miocene age. The oil field occurs on a northeast-dipping mono-

cline against a large, normal fault, known as the Russell fault. This fault trends approximately N. 30° W., and dips steeply to the southwest. The Dibblee sand lies at depths ranging generally from 2,800 to 3,200 feet. The Colgrove zone lies approximately 1,000 feet below the top of the Dibblee.

The South Cuyama field, discovered in May of this year, lies in the foothills at the south margin of the valley, about 4 miles southeast of the Russell Ranch field in Santa Barbara County. Its productive limits have not yet been determined, but present development and productive outposts extend over an area 3 miles long and more than 1½ miles wide. This oil field occurs on an elongated faulted dome, its long axis trending northwest and southeast. Production is from the Dibblee zone, encountered at depths ranging from 4,000 to 4,400 feet. Exploration has not yet been carried below this zone. Unlike the Russell Ranch field, South Cuyama has a gas cap area at the crest of the dome.

The Dibblee sand is a friable, well sorted arkose, ranging from fine- to coarse-grained. It is characterized by high porosity, high permeability, and high productive indices. Potentials in both fields range upward to several thousand barrels per day. The Colgrove sand is similar in character to the Dibblee and well potentials are comparable, though generally somewhat smaller due to the lesser thickness of sand. Both fields are being developed on a ten-acre spacing pattern, with duplicate wells where the Colgrove zone is productive.

10:45 Nomination of Officers.

10:55 (4) GEOLOGY AND PROBLEMS OF EXPLORING FOR OIL IN NORTHERN ALASKA

Col. O. F. Kotick, USA, Naval Petroleum Reserve No. 4, Fairbanks, Alaska (read by Frank Morgan, Richfield Oil Corporation, Los Angeles).

The Arctic is a land of natural excesses and severities. Special problems are presented by the excessively cold temperatures, protracted periods of darkness, winds, fogs, permafrost, and magnetic storms.

The Lisburne limestone (Mississippian) forms prominent scarps and slopes along the north front of the Brooks Mountain Range, which is the northwestern extension of the Rocky Mountains. In the foothill belt north of the mountains, Permian, Triassic, Jurassic, and Cretaceous rocks are represented.

Cretaceous rocks make up the bulk of the drillable sediments of the Arctic basin. These rocks attain a maximum thickness of about 22,000 feet, principally dark shales with some fine, tight sandstones and silts.

Northward thrust faults provide the major structural features along the front of the Brooks Range; this orogeny has resulted in the lower Mesozoic rocks immediately in front of the Range being broken up into a highly complex zone of isoclinal and overturned folds and thrust faults. Farther north the outcropping Cretaceous rocks are gently folded into long east-west trending structures, slightly steeper on the north limbs.

All types of known accepted tools have been or are being used in this exploration project including magnetometer, gravity meter, seismograph, core drill, surface and subsurface geology, aerial photography, and photo-geology, and test wells with all accepted devices for well survey. Eight test wells have been drilled to date, and twelve more are planned through 1952.

The natives, organization and planning for exploration, and the extraneous activities supported by Navy funds are described briefly.

THURSDAY AFTERNOON, 2:00-4:00

Presiding: WILLIAM F. BARBAT, Standard Oil Company of California, San Francisco
LOYDE H. METZNER, Signal Oil and Gas Company, Los Angeles

2:00 (1) OFFSHORE SEISMIC PROBLEMS AFFECTING GEOLOGIC EVALUATION

Curtis H. Johnson, General Petroleum Corporation, Los Angeles, and Robert B. Galeski, Honolulu Oil Corporation, Los Angeles.

During 1948 and 1949 joint seismic operations were conducted offshore the coast of California by a group averaging 14 oil companies employing two crews for a total of 13 crew-months. This joint effort was required by the California Division of Fish and Game to minimize damage to fish. During this work a notable variety of problems were encountered.

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Problems peculiar to marine work are: secondary energy bursts, circumvented by either firing charges shallow or jetting them into the bottom; multiple reflections from the ocean floor, which result in apparent reflections below basement for shallow water, unusable records in water around 500 feet deep and complete repetitions of section for very deep water; occurrence of high angle "erratics," interpreted in terms of faulting, buried stream channels, and bottom irregularities; constant velocity in deep water, handled by projecting shots and detectors to the ocean floor; surveying over vast expanses of water, accomplished by the use of shoran; and timing the programming of specific lines to best overcome bad weather, ocean traffic hazards, and damage to fish.

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Problems peculiar to marine work are: secondary energy bursts, circumvented by either firing charges shallow or jetting them into the bottom; multiple reflections from the ocean floor, which result in apparent reflections below basement for shallow water, unusable records in water around 500 feet deep and complete repetitions of section for very deep water; occurrence of high angle "erratics," interpreted in terms of faulting, buried stream channels, and bottom irregularities; constant velocity in deep water, handled by projecting shots and detectors to the ocean floor; surveying over vast expanses of water, accomplished by the use of shoran; and timing the programming of specific lines to best overcome bad weather, ocean traffic hazards, and damage to fish.

Tactics designed to facilitate geological interpretation involve density of lines and shot points along lines and the use of L-spreads to obtain strike and dip. Factors in the interpretation of seismic results are diagnostic unconformities known in adjacent areas, submarine coring, regional submarine topography, and data from supplementary geophysical methods.

2:25 (2) FLOOR OF LOS ANGELES BASIN¹

J. E. Schoellhamer and A. O. Woodford, United States Geological Survey, Claremont.

The Miocene deposits of the Los Angeles Basin are between the San Gabriel Mountains and the sea, and extend from the Santa Monica Mountains to the Santa Ana Mountains. The sub-Miocene floor is largely composed of crystalline rocks of three types. Southwest of the Newport-Inglewood fault zone and in that zone the crystalline basement is made up of "Catalina schist,"² largely quartz and chlorite, and characterized especially by widespread glaucophane and lawsonite. The other two basement types, cropping out along the north and east margins of the Basin and penetrated in wells near these margins, are slate (and quartzose sandstone), possibly of Triassic age, and quartz diorite (and other quartz plutonites) intrusive into the slates.

In and near the Santa Ana Mountains Cretaceous and early Tertiary sedimentary rocks are intercalated between the slate-plutonite complex and the Miocene volcanic and sedimentary rocks.

The "Catalina schist" contains small masses of zoisite-bearing metagabbros but completely lack normal quartz plutonites. No gradation between the "Catalina schist" and the Triassic(?) slates has been found. The cordierite and other schists at the plutonite-slate contacts in the Santa Monica Mountains are very different from the "Catalina schist." The "Catalina schist" may be much older than the slates.

The surface of the "Catalina schist" west of the Inglewood-Signal Hill line shows great relief, from 1,100 feet above sea-level to 14,500 feet below. Elongate basement ridges trend northwest beneath the Torrance-Wilmington and El Segundo-Lawndale oil fields, somewhat less certainly beneath the Palos Verdes Hills, and considerably less certainly southeastward from the Playa del Rey oil field.

At the northeast edge of the Basin, from Pomona to Puente, the basement surface slopes south-westward about 800 feet to the mile.

The central part of the Los Angeles Basin northeast of the Newport-Inglewood fault zone has a floor that is probably far beneath the depths of 10,000-12,000 feet below sea level reached by the deepest wells. Aeromagnetic strip surveys from Playa del Rey to Pasadena and from the Palos Verdes Hills to the San Jose Hills locally give promise of contributing data on the basement surface but at present are generally inconclusive. The types of basement rock beneath the central deep are unknown, though a discontinuity within the basement has been suggested by seismic evidence.

2:45 (3) LEGAL ASPECT OF TIDELAND CONTROVERSY

William W. Clary, of law firm of O'Melveny and Myers, Los Angeles.

This talk covers the following points: (1) the three classes or types of water area involved, namely, inland waters, marginal sea, and continental shelf, and the present uncertainty about the definition and demarcation of each area; (2) the respective legal rights of States and Federal Government, so far as now determined, in each of the three water areas; also, international aspects of this problem and varying rights of foreign nations under international law in each of these water areas; (3) the present status of the Supreme Court litigation in the California, Texas, and Louisiana cases; (4) the present status of the legislation pending in Congress.

3:15 (4) THEORY OF TRANSGRESSIVE AND REGRESSIVE REEF (BIOHERM) DEVELOPMENT AND ORIGIN OF OIL WITHIN THEM

Theo. A. Link, consultant, Toronto, Ontario and Calgary, Alberta.

Part I

The established geological principle "transgression" and "regression" of epi-continental seas, the resultant sediments, together with their fauna and flora, is applied to coral-reef or bioherm-forming organisms. Bioherms which develop during a transgression are differentiated from those of a retreating sea by the associated sediments. A "transgressive" bioherm is surrounded and overlain by marine clastics deposited during submergence, while the "regressive" type of bioherm is associated with evaporites and/or other types of sediments deposited during withdrawal of the sea.

Part II

It is suggested that hydrocarbons found within coral-reef or bioherm reservoirs are in most instances indigenous, because of the obvious concentration and accumulation of organisms within

¹ Published by permission of the director of the United States Geological Survey.

² Name not adopted by the United States Geological Survey.

them. The porosity and permeability of coral-reef or bioherm reservoirs are attributed not only to the hollow corallites *etc.*, but also to the helter skelter accumulation of them so that, in many instances, such porosity is greater, more effective and more continuous. Partial or entire obliteration of porosity is, in part, due to infiltration of evaporites associated with the regressive type of bioherm.

3:55 (5) WESTERN CANADA SEDIMENTARY BASIN AREA

Theo. A. Link, consultant.

The Sedimentary Basin area of Western Canada which lies between the Pre-Cambrian Shield and the Cordilleran Mountain area, covers approximately 800,000 square miles. Sediments ranging from Cambrian to Tertiary are present, and of these the Upper and Lower Cretaceous, Jurassic, Mississippian, and Devonian have yielded commercial oil and gas fields. Producing zones in the Cretaceous and Jurassic are sandstones, while all of those of the Paleozoic are carbonate rocks such as reef limestones or dolomites (bioherms). Shows of oil and gas have also been encountered in the Cambrian and Triassic sediments.

The broad structural features of this vast expanse of sedimentary rocks are the Moose Jaw syncline, Sweet Grass-Battle River arch, Alberta syncline, the Foothills belt, the Rocky and Mackenzie mountains, the Great Bear-Slave Lake Basin and the Mackenzie Delta Basin area. This contribution is a brief outline of these data with examples of producing oil-field structures and stratigraphic traps.

FRIDAY MORNING, 9:30-12:00

Presiding: LOWELL E. REDWINE, Honolulu Oil Corporation, Santa Barbara

LOYAL E. NELSON, Southern California Petroleum Corporation, Los Angeles.

9:30 (1) GEOLOGY OF PLACERITA CANYON OIL FIELD

Robin Willis, Hildon Oil Company, Los Angeles.

The Placerita Canyon oil field is developed in continental sands of Pico or Saugus age. Saturation occurs through an interval of 700 feet, with 150-400 feet of productive sand, yielding 12°-26° gravity oil.

The structure is a monocline dipping west-northwest at about 25 degrees, closed on the northeast by the San Gabriel fault, and on the south and east by minor faults. Other small faults divide the field into separate pools of varying gravity.

The proven area now covers about 560 acres, of which the intensively developed higher-gravity area (Confusion Hill) includes about 125 acres. The total reserve is estimated at 30 million barrels.

9:45 (2) GEOLOGY OF NORTH SULPHUR MOUNTAIN FIELD, VENTURA COUNTY

I. T. Schwade and Spencer Fine, Richfield Oil Corporation, Ventura, California.

The discovery well, Ojai Fee No. 35, was drilled in 1912, and completed for 100 barrels a day, 22.8° gravity, between 2,387-3,919 feet. In 1942, well No. 44 was drilled as a straight hole to the depth of 8,735 feet, and was completed in the interval, 2,425-4,357 feet. Both wells passed through a thrust fault from Pliocene into Miocene; however, as located, well No. 44 encountered only a small amount of lower Mohnian and was completed largely in older beds. The rediscovery of the field came about in 1947 with the drilling of No. 45 for the purpose of determining the attitude of the fault, and to obtain full information regarding the attitude of the beds and character of the reservoir beneath this fault. From this information a program of directed holes was undertaken to maintain a high structural position beneath the fault and to encounter a greater amount of productive section. Development proceeded east and west to the present size of approximately 1½ miles in length and slightly more than ½ mile in width, and having twenty wells. Cumulative production to July, 1949, when the field was shut in due to general curtailment of lower-gravity crude fields in the state, has been 496,000 barrels, average gravity 19°-20°.

Structurally, the productive zone of Mohnian sands and fractured shales on the east end dips 80° toward the north, overturned; on the west end of the productive zone dips 50°-60° southward, upright. Most wells penetrate the Sisar fault (Miocene over Pliocene) and the North Sulphur Mountain fault (Pliocene over Miocene) in order to reach the productive zone.

10:00 (3) VAQUEROS FORMATION WEST OF SANTA BARBARA, CALIFORNIA

Eugene R. Orwig, Jr., General Petroleum Corporation, Los Angeles, California.

A summary of data is submitted on the Vaqueros formation in the area between Gaviota Pass and Santa Barbara, California. A stratigraphic study was made with particular regard to variations in mass properties, heavy minerals, and age.

The results of field observations and laboratory analysis have indicated maxima of thickness, sorting, permeability, and porosity between Refugio and Bartlett canyons. Mean grain size was observed to have a decreasing trend from west to east. Heavy-mineral assemblages invariably consist of titanite and black opaques, with a subordinate percentage of other resistant minerals. The under-

lying Sespe sands differ markedly in the dominance of epidote over titanite. The sparse megafossils found in this area were of little value in restricting the age of the Vaqueros. Foraminifera of the *Uvigerinella sparsicostata* fauna were collected from the base of the superjacent Rincon formation.

10:15 (4) GEOLOGY OF NORTHERN SANTA ROSA ISLAND

Robert E. Anderson, Signal Oil and Gas Company, Los Angeles, Lowell Redwine and Paul McGovney, Honolulu Oil Corporation, Santa Barbara and Bakersfield.

The stratigraphy of the northern part of Santa Rosa Island is somewhat similar to that of the Santa Barbara Coastal district. These two areas represent, respectively, the southern and northern margins of the Ventura Basin. The Island area mapped offered a section from Pleistocene to Eocene, with Pliocene evidently absent. Formations recognized include marine terraces, Santa Margarita sandstone, Monterey shale, Rincon shale, Vaqueros sandstone, Sespe, Cozy Dell(?) shale, and Matilija(?) sandstone. An interesting time equivalence between the Vaqueros and upper Sespe formations is indicated.

The Santa Rosa fault is the dominant structural feature of the Island. It trends east-west and divides the Island in half. A horizontal displacement of nearly five miles is indicated. Other significant but smaller faults are the Sandy Point, Garanon, and Arlington. Important folds are the Garanon, Tecolote, and Soledad anticlines and the West End and Becher's Bay synclines.

Five wells have been drilled and abandoned on the Island and a sixth is now being drilled.

10:45 (5) OCEAN FLOOR INVESTIGATIONS ALONG SANTA BARBARA COUNTY COAST

Warren C. Thompson, Scripps Institute of Oceanography, La Jolla.

For the increasing number of oil geologists who are studying the submerged shelves of Southern California in order to unravel the bedrock structure, a knowledge of where to look on the sea floor to find bedrock outcrops is highly desirable in saving exploration time and expense. Knowledge of the topography of the shelves is thus required.

The submerged shelf between Point Conception and Santa Barbara is considered. Cross sections of the shelf show that the Recent marine sediment or "overburden" which rests on the bedrock commonly forms a lens-shaped deposit. Within the surf zone, this sediment lens varies from zero to a few feet thick. It thickens offshore to an average of about 40 feet, but in places to more than 100 feet, then usually tapers off to a few feet or less in thickness near the outer edge of the submerged shelf. Isopach charts of overburden aid in conveying the nature of the sediment lens.

The bedrock of the shelf is traversed by numerous canyons and gullies probably Late Pleistocene in age. These have subsequently been alluviated by continental sediment and later by marine sediment so that no topographic expression of them is evident on the ocean floor. These features are illustrated on the submarine bedrock contour charts.

The common giant kelp which forms the extensive kelp beds along this coast (*Macrocystis pyrifera* Linnaeus) is commonly considered to be a good criterion for the presence of bedrock outcrops. This is now known to be partly erroneous, and it is shown that the kelp grows equally well in thick overburden of mud and fine sand. However, by observing the plant density from aerial photography, it can be determined whether the algae is growing on bedrock or in thick sediments.

11:05 (6) RECENT DEVELOPMENT AT GUIJARRAL HILLS

John S. Loofbourow, Jr., Barnsdall Oil Company, Los Angeles.

The Gujarral Hills oil field, located on the Coalinga anticline midway between Pleasant Valley and Kettleman Hills, was discovered by the Barnsdall Oil Company on September 19, 1948. The discovery well produced from the Leda sand. Since then there have been 36 Leda sand wells completed in the field on a 20-acre spacing program. The development has demonstrated that the accumulation is stratigraphic and only the updip or northwest limit of the field has been located. At present, approximately 800 acres of Leda sand production have been proved.

On April 28, 1949, a new zone was discovered by the Barnsdall Oil Company with the completion of Allison A73-34-2 in a sand in the Basal Temblor which was logged approximately 500 feet above the Leda sand. To date, 11 wells have been completed in this zone on a 20-acre spacing program. Indications are that the accumulation is stratigraphic. Approximate limits of production have been defined only on the southeast and at present about 360 acres may be considered as proved.

11:20 (7) REPORT OF PACIFIC COAST SUB-COMMITTEE ON CENOZOIC OF GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

Robert T. White, State Exploration Company, Los Angeles.

11:35 (8) RECENT EXPLORATORY RESULTS IN CALIFORNIA

Graham B. Moody, Standard Oil Company of California, San Francisco.

Analysis of recent exploratory achievements in California indicates that those who have been prone to "view with alarm" the potentialities of California's oil resources have been overly pessimistic. This conclusion is supported by graphs, figures, quotations, and arguments.

FRIDAY AFTERNOON, 2:00-4:00

Presiding: R. B. HUTCHESON, The Superior Oil Company, Bakersfield
WALLACE L. MATJASIC, Honolulu Oil Corporation, Los Angeles

2:00 (1) TIME OF OIL AND GAS ACCUMULATION

A. I. Levorsen, Stanford University.

An idea of the time oil and gas accumulated into pools may be gained through two separate and simple lines of reasoning. These are: (1) a pool can not form until after the trap has been formed. We have several methods of dating geologically the time the trap was formed and consequently setting the time or times before which there could have been little or no accumulation; and (2) the capacity of a trap to contain oil and gas is roughly a function of the pressure in the reservoir. The pressure in turn is related to the depth of burial and the hydrostatic head. Pools full of oil and gas to the spill point have accumulated only under the increasing pressure which comes with burial. Both types of reasoning support the idea that in some pools at least, the accumulation was late in terms of the life of the reservoir rock—accumulation even taking place to the present time.

The PVT relationship of gases may also be used to explain the time of regional migration of oil and gas within basins and provinces. The drilling of a hole into an oil and gas pool, for example, allows the gas to expand as the pressure gradient develops between the pool and the well hole. The expanding gas moves toward the area of lower pressure, either carrying or pushing the oil along with it. Basins and other large geologic units have experienced numerous upsets of their PVT relationships during their history. Tilting, faulting, folding, regional arching, erosion, and deposition all serve to upset the PVT equilibrium from time to time. The development of a pressure gradient through such causes as these makes for the expansion and movement of gas toward the area of lower pressure in a manner similar to what we know exists when a well is drilled into a pool. The available energy may be very large. Local traps which existed prior to the regional movement would collect oil and gas into pools whereas local traps which formed after the regional movement would be barren.

3:00 (2) OBSERVATIONS ON PALEOZOIC STRATIGRAPHY OF CENTRAL NEVADA

Chas. W. Merriam, California Institute of Technology, Pasadena.

3:30 (3) SOME OBSERVATIONS ON GEOLOGICAL STRUCTURES IN EASTERN NEVADA

Fred L. Humphrey, Stanford University.

The White Pine Range of east-central Nevada consists of a central dome of Lower Paleozoic sedimentary rocks and a small granodiorite intrusive, surrounded by sedimentary rocks of Devonian and Carboniferous age. The dome is bounded by arcuate normal faults with maximum vertical displacements of 15,000-18,000 feet. The evidence suggests that the dome has been pushed up, as a unit, into the younger rocks.

The principal structures within the Upper Paleozoic rocks of the Range are folds and thrust faults. At least part of the folding occurred during Eocene time. No evidence of folding of these rocks during the down-warping of the Cordilleran geosyncline was recognized, although any structural traps of that era would be most desirable.

Contained in these Upper Paleozoic rocks is a thick section of the Middle Mississippian White Pine formation, which, although there are rapid facies changes, often contains a considerable thickness of black carbonaceous shales. This formation is general throughout eastern Nevada and could well be a source rock for petroleum providing the structure and surrounding rocks furnish favorable reservoirs.

Other observed areas throughout eastern Nevada have structures generally similar to those within the White Pine district. That is, the rocks are folded and the folds are broken by thrust faults. The thrust faults vary from minor breaks with a few feet of displacement to displacements of several or even tens of miles. The mountain ranges generally furnish some evidence of being bounded by a series of normal faults and there are commonly many normal faults within the ranges.

The presence of volcanic flows need not discourage oil exploration as these have flowed many miles from the source. However, the intrusive rocks, including the dike feeders of lava flows, have altered and metamorphosed the surrounding rocks.

The Upper Paleozoic rocks are probably the only potential source rocks for petroleum in eastern Nevada, although the Ordovician graptolite shales of central Nevada undoubtedly warrant examination, as well as the Triassic marine shales of southern Nevada.

(More about Pacific Section on page 2080)

A.A.P.G. REGIONAL MEETING, BILOXI,
OCTOBER 12-14, 1949. ABSTRACTS

The sun-kissed shores of Mississippi, pleasingly mentioned in the welcoming speech of secretary-treasurer Henry N. Toler, were truly a delightful locale for the regional mid-year meeting of the Association at Biloxi, on October 12-14. The Gulf, the breeze, the sunshine were perfect for dock and deep-water fishing for those who sought recreation after, and before, the technical program. Nearly 600 members, wives, and friends attended the meeting. The Buena Vista Hotel was the comfortably appointed headquarters for registration and all events. Its new air-conditioned Hurricane Room on the lobby floor is well arranged for scientific sessions and entertainment.

The preliminary sessions on Wednesday afternoon gave the committees working on Mesozoic and Cenozoic stratigraphic correlations their opportunity to report progress. Frederic F. Mellen of Jackson, Mississippi, and Grover E. Murray of Baton Rouge, Louisiana, presided at these respective discussions.

On Thursday morning, Tom H. Philpott, of Shreveport, Louisiana, general chairman of arrangements, presided at the first session, and secretary Toler of Jackson, Mississippi, and president C. W. Tomlinson of Ardmore, Oklahoma, officially opened the meeting. Twenty-two papers were on the program, ranging geographically throughout the Gulf Coastal Plain, including East Texas, Louisiana, Arkansas, Mississippi, Alabama, Georgia, and Florida.

Guidebooks of earlier field trips of several affiliated societies (Shreveport, Mississippi, and Southeastern) were on sale near the registration counter, and stratigraphic cross sections were also on exhibition on large bulletin boards in the lobby.

As a preview of Oil Progress week, three service companies demonstrated marine equipment used in offshore operations. These exhibitions were held on the beach opposite the Buena Vista Hotel. Bell Aircraft, Core Laboratories, and Schlumberger Well Surveying Corporation had appreciative audiences. The performance of the Bell Aircraft helicopter so absorbed the attention of the crowd that the resultant near-traffic jam went nearly unnoticed.

Air trips were arranged for members desiring to see offshore drilling rigs; twenty-four persons went in donated planes along the coast to Grand Isle and back across the Mississippi delta. Flying conditions were pronounced perfect.

The luncheon for the ladies on Thursday at the White House was under the auspices of the Ladies Auxiliary of the South Louisiana Geological Society. Sixty-three enjoyed this event. Entertainment for 100 ladies was afforded by a Bingo party in the parlors of the Buena Vista. Prizes were donated by the Jack Riley Blueprint Company of Shreveport, and the Beaumont Cement Sales of Lake Charles.

The dance on Thursday night was held in the Hurricane Room of the Buena Vista.

This meeting was unusual in that it was arranged by a committee representing seven local societies: the South Louisiana Geological Society, the New Orleans Geological Society, the East Texas Geological Society, the Shreveport Geological Society, the Mississippi Geological Society, the Southeastern Geological Society, and the Ark-La-Tex Geophysical Society. The committee chairmen, whose work resulted in this second successful regional meeting at Biloxi, are the following.

General Chairman: T. H. PHILPOTT, Carter Oil Company, Shreveport

Hotels: M. N. BROUGHTON, Texas Company, New Orleans

Publicity: HASTINGS MOORE, Danciger Oil and Refining Company, Henderson, Texas

Publications: L. R. MCFARLAND, Magnolia Petroleum Company, Jackson

Field Excursions: D. E. NEWLAND, consultant, Lake Charles

Entertainment: LESLIE BOWLING, consultant, New Orleans

Technical Equipment: GROVER E. MURRAY, Louisiana State University, Baton Rouge

Financial: CHARLES A. HICKCOX, Centenary College, Shreveport



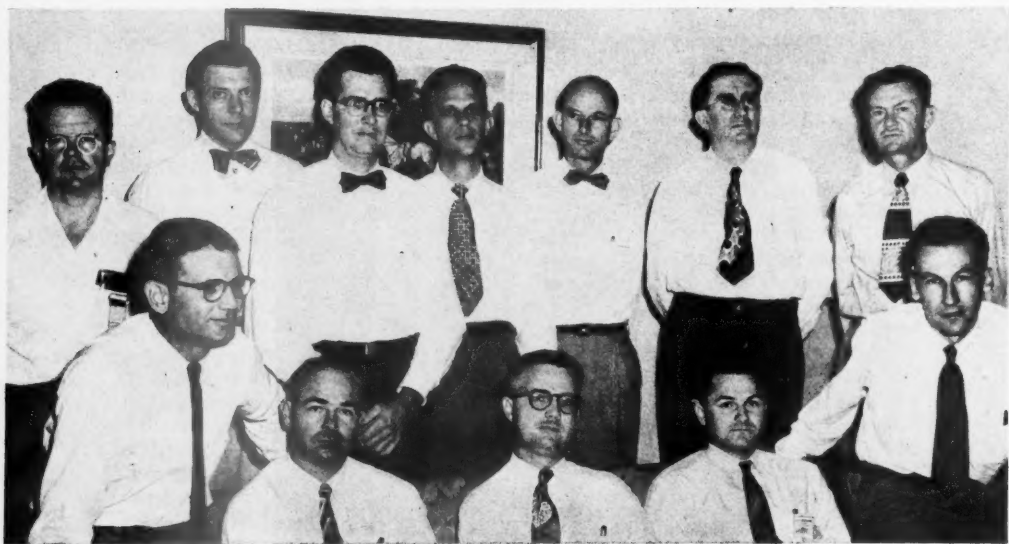
1. Biloxi meeting. General chairman Tom Philpott, Carter Oil Company, Shreveport, Louisiana, presided in Hurricane Room of Buena Vista Hotel.



2. Biloxi meeting. Secretary-treasurer Henry N. Toler, Southern Natural Gas Company, Jackson, Mississippi, welcomed everybody to his native state.



3. Biloxi meeting. President C.W. Tomlinson, of Ardmore, Oklahoma, addressed members and friends. Seated: T. R. Eskrigge, Gulf Oil Corporation, Harvey, Louisiana, represented past-president Paul Weaver who was absent.



4. Officers and committeemen at Biloxi meeting. Front, left to right: W. B. Neil, Stanolind Oil and Gas Company, Lake Charles, Louisiana, president of South Louisiana Geological Society; Dee E. Newland, consultant, Lake Charles, chairman, field-trips committee; Thomas H. Philpott, Carter Oil Company, Shreveport, general chairman of meeting; Lawrence J. Finrock, Carter Oil Company, Jackson, Mississippi, assistant chairman, publications committee; and James L. Martin, Jr., Sinclair Oil and Gas Company, Jackson, general committee. Back row: Charles A. Hickox, Centenary College, Shreveport, chairman, finance committee; Fred M. Schall, Jr., Big Chief Drilling Company, Shreveport, general committee; Grover E. Murray, Louisiana State University, Baton Rouge, chairman, technical-equipment; Charles DeBlieux, consulting geologist, New Orleans, treasurer, New Orleans Geological Society; Leslie Bowling, consulting geologist, New Orleans, president, New Orleans Geological Society; Hastings Moore, Danciger Oil and Refining Company, Henderson, Texas, chairman, publicity; and George E. Wagoner, Carter Oil Company, Shreveport, vice-president, S.E.G.

ABSTRACTS

1. "Geosynclinal Sedimentation in Central Gulf Region of United States," Grover E. Murray, Louisiana State University, Baton Rouge, Louisiana.

More than 30,000 feet of Mesozoic and Cenozoic sediments are present in the central Gulf region of southern United States. They constitute a great sedimentary complex (Gulf Coast geosyncline) composed of marine and deltaic deposits. The deltaic sediments occur as overlapping ladle-shaped and irregularly lenticular masses with areas of maximum accumulation (depocenters) in general parallel with the coast line. Individual deltaic masses coalesce to form elongate, geosynclinal deltaic complexes. Thin marine strata are present between the deltaic depocenters; thick marine sediments occur on the seaward edges of the deltaic masses. Landward, currently updip, both the marine and deltaic units are replaced by marginal and fluvial deposits; seaward, the marine facies are deeper-water and the deltaic facies are more marine.

Three major depositional stages are represented: a lower, marginal-deltaic stage; a middle, marine stage; and an upper, marginal deltaic stage. These primary stages coincide with major fluctuations of sea-level. Minor depositional stages and sea-level fluctuations complicate the sedimentary history of the area.

Axes of maximum deposition shifted from time to time in position and alignment and progressed generally in a seaward direction. Major interruptions of the seaward progression occurred in the Cretaceous and Tertiary. The geographic positions and stratigraphic thicknesses of these depositional axes are shown on maps and cross sections.

The stratigraphic and sedimentary history of the area, along with Recent geologic events, indicate that subsidence has been a major factor in creating a linear, arcuate geosyncline in the Gulf Coastal Plain of the United States.

2. "Control of Petroleum Accumulation by Sedimentary Facies in South Louisiana," Max Bornhauser, Continental Oil Company, Houston, Texas.

This paper, with the aid of electric logs and cross sections, presents some new ideas concerning the effects of sedimentary facies upon the accumulation of oil in south-central Louisiana. It covers the section from the Wilcox to the Cockfield.

3. "Structure of South Louisiana Deep-Seated Domes," W. E. Wallace, Sohio Petroleum Company, Lafayette, Louisiana.

This paper is a continuation and re-examination of a paper of the same title published in the *Bulletin* in September, 1944. Structure maps and cross sections of several heretofore unpublished fields are included, with a discussion of later trends of thought about the nature of deep-seated domes.

4. "New Method of Local and Regional Correlation, Using Resistivity Value from Electrical Logs," A. Claudet, Schlumberger Well Surveying Corporation, New Orleans, Louisiana.

A method is presented of correlating electrical logs of specific sub-strata penetrated by the drill over very short or very long distances by the use of exact resistivity values of the shales.

Cross sections showing the subsurface correlation derived from electrical logs recorded on wells spaced over large distances in Mississippi and Louisiana illustrate the resistivity changes in shales which occur with changes in locations or geological age.

These clay or shale resistivity gradients may be extrapolated for distances of about 50 miles so that correlations may be anticipated at the new locations. This method of using the exact values of the shale resistivities provides an important tool for subsurface correlation by means of the electrical log. The silhouette of the curves of the electrical logs opposite sand sections has been used for many years for correlation.

The method discussed gives invaluable added factors which will help in eliminating uncertainties in subsurface correlation. It will also help in a general study of sedimentary cycles and local structures.

5. "Interior Salt Domes of East Texas," G. C. Clark, Stanolind Oil and Gas Company, Tyler, Texas.

(From report prepared by L. S. Melzer and G. C. Clark)

In the East Texas district, 27 salt domes have been definitely identified. Of this number, 10 are classed as deep-seated and 17 as piercement. Two of the piercement domes, Boggy Creek and Kittrell, are found to be productive from the Woodbine and the lower Claiborne respectively. Seven deep-seated domes are found to be productive from formations varying in age from Comanche to Nacatoch. All domes, both deep-seated and piercement, are reflected as gravity minima, with the exception of Marquez and Kittrell which are shown by gravity surveys as maxima.

All piercement domes in the East Texas district grew from the deepest part of local synclines and all are situated within the regional province known as the Tyler basin. The Upper Cretaceous

beds are found to thicken and dip steeply away from the salt core, indicating structural movement both during and after deposition. Thinning of Upper Cretaceous sediments over the deeper-seated domes where the evidence has not been obliterated confirms this structural growth. The basin position of these domes and the time of origin indicates that the Lower Cretaceous sediments dip toward the domes.

Deep-seated domes are found to have many of the aspects of anticlinal structures. These domes began their growth much earlier than piercement domes and are located, and have always been located, on locally high areas. Thinning of Lower Cretaceous sediments furnishes evidence for their early origin, and uniform thinning of Upper Cretaceous beds suggests that these domes grew uniformly throughout Upper Cretaceous and Tertiary time and were never subjected to the violent displacements which affected their neighbors, the piercement domes. These structures are ideal reservoir anomalies and seven out of ten are now producing, with the possibility that some of the others will produce with subsequent development.

6. "Merigale-Paul Field, Wood County, Texas," Hastings Moore, Danciger Oil and Refining Company, Henderson, Texas. Prior to 1947, this field was classified as two separate fields—Merigale and Norman-Paul fields.

The Merigale-Paul field in central Wood County is the most important sub-Clarksville (upper Eagle Ford) reserve now known.

The Merigale-Paul field was discovered in December, 1944, by Bobby Manziel. As of July 1, 1949, the field had produced 3,269,813 barrels from 160 sub-Clarksville wells and 64,790 barrels from the single Woodbine producer.

The oil column is 235 feet; maximum net effective sand thickness is 38 feet, with the average about 16 feet.

Reservoir energy is gas expansion plus a probable limited water drive.

Structurally the Merigale-Paul field is a faulted monocline dipping southeastward, 550 feet to the mile. The trapping fault is a low-angle continental fault (average dip 32°), which parallels very closely the strike of the strata.

The eastern end of the field is at the intersection of the water table with the fault zone, and the western end is at the facies change of the sub-Clarksville sands into ash beds.

7. "Blackfoot Field, Anderson County, Texas," D. O. Branson, Stanolind Oil and Gas Company, Tyler, Texas.

This paper presents a review of the structure, stratigraphy, and history of the Blackfoot field, Anderson County, Texas.

The Blackfoot producing structure is a relatively small, faulted, elongate, domal, closure situated on an anticlinal trend which extends from northeastern Freestone County through west-central Anderson County into southeastern Henderson County and is known as the Blackfoot-Bradford Tennessee Colony trend.

Productive formations include the Rodessa and Pettit limestones, and the Travis Peak sands of the Trinity group. The productive limits are not defined since the field is only partly developed.

Faulting, although present at Blackfoot, is thought to be of minor significance and known faulting does not effect the local accumulation of gas and oil. Control furnished by development wells shows a typical graben fault pattern; however, the exceptional feature in Blackfoot is the termination of both faults at the point of intersection.

8. "Petroleum Exploration in Eastern Arkansas," C. A. Renfro, Arkansas Resources and Development Commission, Division of Geology, Little Rock, Arkansas.

The area with which this paper is concerned lies in the Gulf Coastal Plain in Arkansas north of the Arkansas River. The following conclusions are based on a study of the available samples and electric logs.

Tertiary rocks are for the most part non-marine in origin. Some of the beds in the Jackson and Claiborne groups may be thin tongues of either marine, deltaic, lagoonal, or estuarine deposits. The Wilcox group is predominantly thick, coarse-grained sandstones which are ordinarily water-bearing. The Midway group consists of two formations: the Porters Creek clay and the Clayton. None of the Tertiary rocks is considered promising as a potential oil reservoir.

In the Cretaceous two formations offer possibilities for oil and gas: the Nacatoch sandstone and a basal transgressive sandstone, probably Ozan in age overlying the Paleozoic floor. The Nacatoch is of sufficient thickness and porosity to serve as a reservoir bed. However, local variations in porosity or in the sand-shale ratio should be expected. The basal sand is coarse- to medium-grained, commonly pyritic and glauconitic. Electric logs show a well developed self-potential curve in this unit. If found on structure or as a wedge-edge pinch-out, this basal sand has good possibilities as a future oil source.

Paleozoic rocks, ranging in age from Pennsylvanian to Cambro-Ordovician, are present below the Cretaceous. A paleogeographic map of the pre-Cretaceous surface shows that older Paleozoic

formations (Plattin, *et cetera*) are found as far south as Cross and Crittenden counties. This indicates a marked change in strike of the truncated older rocks. With sufficient cover these older beds may be excellent oil traps. The St. Peter sandstone is considered a particularly good possibility.

There is also a possibility that oil traps may be associated with intrusive igneous bodies similar to the nepheline syenite plugs near Little Rock.

9. "Surface and Subsurface Correlation of Wilcox Formation in West-Central Louisiana," D. A. Robertson, C. M. Schwartz, and A. H. Trowbridge. (Work completed as students of Centenary College, Shreveport, Louisiana).

Surface samples of the Wilcox and Midway formations were collected and examined for lithologic characteristics and faunal content. These formations exhibit a cyclic pattern of deposition. Fossils are rare.

The surface equivalents were examined in the subsurface and it was noted that the cyclic pattern exhibited in the outcropping formations extended with marked regularity into the subsurface.

Microfossils and macrofossils were examined from cuttings and a number of these were used along with the cyclic pattern, to correlate the surface formations with their equivalents in the subsurface.

10. "Cairo Field, Union County, Arkansas," L. A. Goebels, The Carter Oil Company, Shreveport, Louisiana.

The Cairo field was discovered in July, 1948. Production is from the Reynolds oölite member of the Smackover limestone of Jurassic age. The field is almost completely developed with 15 producing oil wells and 3 dry holes. The reservoir does not have a gas cap. The structure of the field is essentially an anticline trending northeast-southwest and oddly enough at right angles to the Schuler structure. There are no indications of faulting. The Cairo field is unique in several features. 1. Although regionally updip from the Schuler field, its apex is almost 100 feet lower than that of Schuler. Wells on the west flank of Cairo produce oil 180 feet below the oil-water contact at Schuler. 2. It is the first field in South Arkansas to show definite south limits of the Buckner red shale and anhydrite section. 3. Each producing well has a different oil-water contact. Evidence can be shown to support the theory that the various oil-water contacts are part of a tilted surface rather than the result of different zones of porosity. 4. Wells on the east side of the field where the oil-water contact is high recover oil-saturated porous limestone in cores but on drill-stem tests recover salt water. The subsea depth of 7,540 feet appears to have been the original oil-water contact. Factors which might have affected the original oil-water contact are discussed.

High recoveries with the diamond core-barrel and a complete analysis of all cores made possible a detailed study of the lithologic character of the oölitic limestone. Oölite zones vary laterally and vertically and it is difficult to correlate them from one well to another. The highly porous, loosely cemented oölite zones are best developed in the central and south portions of the field. The transition from clastic to chemical deposition is evident in the top of the Smackover on the north flank of the structure. There is no evidence to suggest that the structure is of reef origin.

11. "Facies Changes in Gulf Cretaceous Beds in Mississippi," Tom McGlothlin, consultant, Laurel, Mississippi.

It has long been recognized that facies changes occur within Gulf Cretaceous beds in Mississippi. Sands which are marginal or near-shore deposits grade to dark gray shales which are considered deeper-water deposits. Red "non-marine" type shales grade to dark gray "marine" shales.

In tracing the various stratigraphic units across the state, it becomes apparent that the base of the Gulf Cretaceous chalk is not a true time line. Neither is the top of "the Marine Tuscaloosa shale."

By noting the general direction of the facies changes in Gulf Cretaceous beds, it is possible to establish in general the direction of the depositional strike and thus arrive at an estimate of the general direction of the shore line of the Gulf Cretaceous seas.

12. "Brookhaven Field, Lincoln County, Mississippi,"¹ Robert Womack, Jr.,² The California Company, New Orleans, Louisiana.

The Brookhaven oil field, located in Lincoln County, Mississippi, was discovered in 1943. A period of inactivity followed, due to poor results of the discovery well. In 1945 the second producer was completed which led to the development of the field. The Brookhaven structure is anticlinal and is probably due to deep-seated salt movement. The structure is crossed by three normal faults which

¹ Presented by permission of The California Company.

² The writer wishes to express his appreciation to the Brookhaven Unit Operators for permission to present the structure and isopachous maps of the lower Tuscaloosa formation and to give full credit for the preparation of these maps to the Brookhaven Geological Committee.

form a central graben area. Production is obtained at an average depth of 10,135 to 10,545 feet from the Tuscaloosa formation of Upper Cretaceous age. Accumulation is controlled by structure and the lenticularity of the producing sands. The faulting present does not affect the accumulation.

After the slow start the field was developed rapidly due to early expiration of the leases. It was noted during the early production history that the reservoir pressures were declining rapidly. This led to a study of the reservoir conditions that resulted in a voluntary unitization agreement among the various operators and royalty owners for a pressure maintenance program to prolong the life of the field and to increase the ultimate recovery.

13. "LaGrange Oil Field, Adams County, Mississippi," M. W. Sherwin, Sohio Petroleum Company, Houston, Texas.

The LaGrange field, Adams County, Mississippi, is the largest field producing from the Wilcox in Mississippi. Originally a Tuscaloosa field opener in February, 1946, the discovery well was plugged back and recompleted as a Wilcox producer in August of the same year. Production is being recovered from several sands of the middle Wilcox at a depth of approximately 6,200 feet. In its short life, the field has been extended to encompass 3,000 acres. As of January 1, 1949, it had 99 producing wells (including 19 twins) and had a cumulative production of more than 3 million barrels. Daily runs are in excess of 11,000 barrels. With the field still not completely defined, eventual production is estimated in excess of 15 million barrels.

The field is located on the flank of the Mississippi basin. The local structure is an elongate west of south-trending anticlinal nose. Although closure is developed on a series of nodes along the axis of the fold, reservoir traps are, in good part, controlled by stratigraphic conditions. Discovery of the field resulted from combination of geophysical and subsurface information.

14. "Occurrence of the Genus *Choffatella* in Wells in South Florida and at Other Localities,"¹ Louise Jordan, Sun Oil Company, Tallahassee, Florida, and Esther R. Applin, U. S. Geological Survey, Tallahassee, Florida.

The paper discusses the occurrence of the genus *Choffatella* in deep wells in south Florida and at other localities in the Atlantic and Gulf Coastal Plain of the United States. The limited stratigraphic range of the genus and its value for correlation are mentioned and a few diagnostic structural features are illustrated with plate figures. The ecology of *Choffatella* is suggested, and occurrences in other portions of the western hemisphere are listed.

15. "Drilling Difficulties in the North Florida-South Georgia Area," Donald J. Munroe, Sun Oil Company, Tallahassee, Florida.

16. "Stratigraphic, Structural, and Correlation Studies of Florida Tertiary,"² Robert O. Vernon, Florida Geological Survey, Tallahassee, Florida.

The completion of field work in Citrus and Levy counties, Florida, has made it possible to redefine the "Ocala limestone" and restrict the term to the upper Jackson upper Eocene; to erect a new formation containing two members that compose the lower Jackson group; and to provide exact horizons in the Jackson on which structural maps can be accurately drawn. These shallow beds are usually reached by water wells and are readily accessible for exploratory drilling. The beds are probably the most distinctive in Florida and are divisible both lithologically and paleontologically.

A distinct unconformity is present at the base of the Jackson group in the area and is recognized by gravel beds in the base of the Jackson and by overlap of eroded middle Eocene limestone.

The division and correlation of the Jackson group have been recognized in approximately 600 wells and a structural map has been constructed, drawn on the top of the lower member of the lower Jackson group. Three well developed shear zones have been recognized. These faults have been dated as probably pre-Miocene, post-Oligocene and isopachs of the Miocene indicate filling of grabens and overlaps of areas standing high during the Miocene. The Hawthorn formation of lower Miocene age appears to be equivalent to the phosphate fixation period during which time the hard rock phosphate of Florida was formed—the Hawthorn is thus correlated with beds included in the Alachua formation, formerly thought to be Pliocene.

17. "Preliminary Report on Buried Pre-Mesozoic Rocks in Florida and Adjacent States,"³ Paul L. Applin, U. S. Geological Survey, Tallahassee Florida.

In the southeastern Coastal Plain, information is available on 60 widely scattered oil test wells that have been drilled through the Cenozoic and Mesozoic deposits into older rocks representing a wide variety of types.

In Florida and Georgia these buried pre-Mesozoic rocks fall in three general classifications which are:

¹ Published by permission of the director of the U. S. Geological Survey, and the Sun Oil Company.

² Published by permission of the Florida Geological Survey.

³ Published by permission of the director of the U. S. Geological Survey.

1. Dominantly marine sedimentary Paleozoic rocks that at present are known to range in age from late Cambrian or early Ordovician to Silurian.
2. Volcanic rocks which underlie sedimentary rocks considered to be of early Paleozoic age.
3. Crystalline rocks that are chiefly granitic and metamorphic. These rocks are possibly in part pre-Cambrian and in part Paleozoic in age.

In the Coastal Plain of Alabama, the buried pre-Mesozoic rocks are classified as:

1. Paleozoic sedimentary rocks that range in age from Cambrian and Ordovician to Pennsylvanian.
2. Metamorphic rocks that are possibly pre-Cambrian in age.

The volcanic rocks that underlie the early Paleozoic sedimentary rocks in Florida and Georgia have not been discovered in Alabama.

Most of the wells in the pre-Mesozoic rocks have been drilled within the past decade, and in Florida and southern Georgia the discovery of volcanic and crystalline rocks and Paleozoic strata is a comparatively recent addition to geologic knowledge. One map shows the location of the wells penetrating the pre-Mesozoic rocks and the types of rocks penetrated. Based on the study of cores and cuttings in connection with the geographic distribution of the wells, a diverse lithologic pattern is being revealed in the pre-Mesozoic rocks of the subsurface in the southeastern Coastal Plain. By means of contours drawn at 1,000-foot intervals on top of the pre-Mesozoic rocks, a second map shows the present configuration of the surface of these rocks. Two structural profiles drawn through series of wells in Georgia and Florida show an interpretation of the present structure of the pre-Mesozoic rocks and the relation of the overlying Mesozoic and Cenozoic deposits to the pre-Mesozoic surface.

18. "Geophysical Case History of Mississippi Salt-Dome Basin," L. L. Nettleton, Gravity Meter Exploration Company, Houston, Texas.

In recent years, the Society of Exploration Geophysicists has published case histories of many individual oil field structures. Of broader interest is the exploration history of a geological unit as a whole rather than its individual structures. The Mississippi salt basin, with its comparatively short period of intense geophysical activity, using modern methods, is an outstanding example of successful application of modern geophysical techniques to a large but limited geologic province.

This paper reviews the history of the geophysical operations in the south Mississippi salt basin, including the nature of the exploration carried out by different companies and their results in terms of later findings by the drill. This paper would not have been possible without the cooperation of the various companies who have contributed the information assembled and grateful appreciation of their help is acknowledged.

19. "Applied Radar in Gulf of Mexico," Orville E. Haley, McCollum Exploration Company.
20. "Offshore Geophysical Operations," a recent kodachrome sound picture furnished by the California Company.
21. "The Part Helicopters are Playing in Geophysical Exploration," E. E. Gustafson, Bell Aircraft Supply Corporation.

Eighteen months of research and development have conclusively proven that helicopters are playing an important part in gravity and seismic operations in remote areas, such as southern Louisiana marshlands, jungles, and mountainous areas where transportation is a difficult problem. Airborne gravity and seismic operations are successfully being carried on with resulting increased production and lowered costs. Discussions on techniques used in gravity and seismic airborne operations, plus a film showing actual field operations as well as flight performance, load-carrying abilities, landing areas, weather restrictions, and maintenance requirements for mobile operations and the possible uses of the helicopter in the oil industry, will be discussed in detail.

22. "Oceanographic and Meteorological Aspects of Geophysical Prospecting," Alfred H. Glenn, Alfred H. Glenn and Associates, New Orleans, Louisiana, and Charles C. Bates, consultant to A. H. Glenn and Associates, and oceanographer, U. S. Navy Hydrographic Office, Washington, D. C.

Oceanography and meteorology, the latest earth sciences used on a consultant basis by the petroleum industry, are first reviewed in general terms and then from the point of view of the petroleum geophysicist. Actual and potential applications of these sciences are shown to exist in the planning and operational phases of exploration geophysics. The sources of oceanographic and meteorological information are discussed with respect to these applications.

A.A.P.G. REGIONAL MEETING, BANFF, SEPTEMBER 5-8, 1950¹L. M. CLARK²

Calgary, Alberta

Announcement.—A regional meeting of the A.A.P.G. will be held under the auspices of the Alberta Society of Petroleum Geologists, at the Banff Springs Hotel, Banff, Alberta, Canada, September 5-8, 1950. The meeting will be held jointly with the Society of Exploration Geophysicists and the Geological Association of Canada. The meeting is being arranged under the general chairmanship of LESLIE M. CLARK, Barnsdall Oil Company, Calgary, Alberta.

Hotel reservations.—Hotel reservations will *not* be accepted at this early date. Application forms will be mailed later.

Technical program.—Papers for the petroleum part of the technical program are currently being solicited and prepared to cover regional aspects of the Canadian Rockies and western Canada, as well as specific oil and gas fields. Other papers are planned by the Society of Exploration Geophysicists and the Geological Association of Canada to be presented concurrently. The technical program committee of the A.S.P.G. is headed by A. J. GOODMAN, Socony-Vacuum Exploration Company, Calgary.

Field trips.—Field trips will be held, as part of the program, to include Paleozoic and Mesozoic stratigraphy and to illustrate various phases of the structure of the Canadian Rockies and the adjoining Foothills belt. The field trip committee is headed by D. B. LAYER, Imperial Oil Limited, Calgary.

Entertainment.—Entertainment plans are being formulated for the benefit of members and their families and others attending the meeting. The entertainment committee is headed by A. R. WINZELER, Stanolind Oil and Gas Company, Calgary.

Other committee chairmen appointed to date are: *Publicity*, N. W. NICOLS, Rio Bravo Oil Company, Calgary; *Hotel and Registration*, B. H. COREY, Canadian Pacific Railway, Calgary; *Finance*, GEORGE FURNIVAL, California Standard Company, Calgary.

More detailed notices will appear later. Application forms for reservations also will be sent at a later date. It is hoped that this early reminder will result in as many as possible making tentative plans for attendance.

¹ Manuscript received, November 3, 1949.

² General chairman.

A.A.P.G. ANNUAL MEETING, CHICAGO, APRIL 24-27, 1950

The 35th annual meeting of the Association will be held at the Stevens Hotel, Chicago, on April 24-27, 1950. The executive committee is in charge of arrangements. Concurrent and joint sessions will be held as usual by the Society of Economic Paleontologists and Mineralogists (April 25-27) and the Society of Exploration Geophysicists (April 24-26).

Technical program.—President C. W. TOMLINSON has appointed LYNN K. LEE, manager of exploration, Pure Oil Company, Chicago, to serve as chairman of the technical program. Plans are well under way for a series of technical sessions involving themes which are believed to be of outstanding interest. One such theme will be a review and revision of "Possible Future Oil Provinces of the United States and Canada," with additional parts of North America to be included. MAX W. BALL, formerly chief of the Oil and Gas Division of the United States Department of the Interior and now engaged in consulting work in Washington, D. C., is chairman of a committee to organize this part of the program.

GLENN C. CLARK, staff geological adviser, Continental Oil Company, Ponca City, Oklahoma, is chairman of a committee to prepare a review of the trapping components in the various important producing provinces of the United States. The papers in this program will review the various types of hydrocarbon accumulations, their relative economic importance, and the problems of exploration. These two symposia are believed to be timely in view of the large recent increase in membership of the Association.

The joint societies, through their program chairmen, have appointed GAIL F. MOULTON of the Chase National Bank, New York City, as chairman of a committee to secure outstanding speakers for a non-technical program.

Members planning to submit papers not involved in the symposia described should notify LYNN K. LEE, Pure Oil Company, 35 East Wacker Drive, Chicago, Illinois, by January 1, giving the title and length of their papers. Abstracts, in duplicate, double-spaced, are due on or before February 1. Authors must notify the chairman about the number, size, and nature of the slides they desire to use, in order that proper projection may be arranged. Simplify your slides; excessive details are unsatisfactory. Will you use black and white or kodachrome?

S.E.P.M. technical program.—In addition to presidential addresses and joint sessions with the other two exploratory societies, the S.E.P.M. program will include technical sessions and a symposium. The symposium, under the direction of the research committee, will be on "Problems in Marine Geology" and will include papers by outstanding authorities.

President H. B. STENZEL has appointed L. L. SLOSS, department of geology, Northwestern University, Evanston, Illinois, to be program chairman for the S.E.P.M. Members planning to submit papers should notify the program chairman by January 1 of the title and length of their papers. Abstracts, typewritten, double-spaced, and in duplicate, are due on or before February 1.

Entertainment.—The annual dinner-dance in the Stevens Grand Ball Room is being planned for the last night, Thursday, April 27. Arrangements are being made for orchestra and special entertainment. Dinner-dance tickets will be available at the registration counter during the early days of the meeting. W. C. KRUMBEIN, department of geology, Northwestern University, Evanston, Illinois, is in charge of entertainment.

Exhibits.—Scientific exhibits may be placed in the Third Floor Corridor. These displays will occupy the vertical wall; each exhibit should be designed to occupy preferably not more than 6 feet by 6 feet. Exhibitors are to be scientific, educational, and governmental institutions. Inquiries should be sent to A.A.P.G. Headquarters, Box 979, Tulsa 1, Oklahoma.

Commercial exhibits will be arranged on the Mezzanine. Announcements and plans will be mailed to prospective exhibitors. Inquiries may be directed to E. W. ELLSWORTH, assistant business manager, Box 979, Tulsa 1, Oklahoma.

Room reservations.—For convenience in handling requests for hotel room reservations, a specially printed business-reply card has been mailed each member of the three societies. This card is to be returned promptly (preferably not later than March 1) to the Stevens Hotel. All meetings are to be held at the Stevens, which is the headquarters for the convention.

(1) If you will plan to arrive in Chicago on Sunday, April 23, you will be able to obtain your room more promptly and avoid the inevitable delay which will occur if you do not arrive until Monday, April 24.

(2) Group reservations (blocks of rooms) are to be discouraged. The number of suites is limited.

(3) Name and address of each individual desiring occupancy should be given, with type of room desired, arrival date and approximate hour and departure date.

There will be no housing committee. Requests for reservations should be made direct with the Stevens. When the Stevens has exhausted its facilities it will refer additional requests to the Congress Hotel, $1\frac{1}{2}$ blocks away, and to other hotels.

Members, chairmen, representatives, speakers, exhibitors, all should make their own reservations direct with the hotel. Confirmation of reservation will be sent you by the hotel.

DAILY RATES AT THE STEVENS

Single room, one person.....	\$ 4.50-\$10.00
Double room, with double bed, two persons.....	7.50- 12.50
Double room, with twin beds, two persons.....	8.50- 15.00
Suites, comprising living room and bedroom.....	18.00- up

TENTATIVE OUTLINE OF EVENTS

SUN., APR. 23	A.M.-P.M. A.A.P.G. Executive Committee
	P.M. A.A.P.G.—S.E.P.M.—S.E.G. registration
MON., APR. 24	A.M.-P.M. A.A.P.G. Business and other committees
	S.E.G. Technical and business sessions
	Night A.A.P.G. Research committee open session
TUES. APR. 25	A.M. Joint session. Presidential addresses and awards
	P.M. Joint session
WED., APR. 26	A.M.-P.M. A.A.P.G. Technical sessions
	S.E.G. Technical sessions
	S.E.P.M. Technical sessions
THURS., APR. 27	A.M.-P.M. A.A.P.G. Technical and business sessions
	S.E.P.M. Technical and business sessions
	Night Annual dinner-dance

A.A.P.G. REGIONAL MEETING, OKLAHOMA CITY, JANUARY 12-13, 1950

The Oklahoma City Geological Society is arranging the A.A.P.G. Mid-Continent regional conference to be held at Oklahoma City on January 12 and 13, 1950. The list of authors and their papers is included in the announcement which has been mailed to members. The subject matter is restricted to Mid-Continent geology. The Skirvin Tower Hotel is headquarters. Request for room reservation should be made on the form attached to the mailed announcement. It should be sent to the Skirvin Tower without delay as other events in Oklahoma City at the same time require desirable hotel space. The ladies will be entertained at a tea and style show on Thursday afternoon, January 12. Committee chairmen in charge of arrangements are: HUBERT E. BALE, of Kirkpatrick and Bale, Inc., general chairman; ROLAND W. LAUGHLIN, of Laughlin-Simmons and Company, reception and registration; F. H. KATE, 608 Colcord Building, program; R. W. BIGGART, finance; E. W. PRICE, Stanolind Oil and Gas Company, entertainment. Officers of the Oklahoma City Geological Society are: president, RIZER EVERETT, Carter Oil Company; vice-president, RICHARD L. ROBERTS, Vickers Petroleum Company; secretary, L. W. CURTIS, Sohio Petroleum Company; treasurer, JOSEPH M. SEARS, independent.

MEMORIAL

RICHARD ROBBINS CRANDALL

(1902-1949)

The geological profession in California has recently experienced a great loss in the death of Richard Robbins Crandall who died on April 16, 1949, at the Huntington Memorial Hospital in Pasadena, at the age of 47. Mr. Crandall had been ill several times during the past 2 years, but was thought to be recovering nicely.

Dick, as he was affectionately known to his friends and business associates, was born in Spencer, Iowa on January 14, 1902. His father, Dr. Walter G. Crandall, and family



RICHARD ROBBINS CRANDALL

moved to Los Angeles in time for Dick to attend Los Angeles High School. Dick entered California Institute of Technology in 1919, but after the first year transferred to Stanford University. At Stanford, he was a brilliant student, graduating *magna cum laude* in 1923.

While at Stanford he was a member of Phi Beta Kappa, Phi Kappa Sigma, and the Geological and Mining Society of American Universities. He continued his active interest in organizations after graduation, joining the American Association of Petroleum Geologists in 1924, and at the time of his death was a member of the Branner Club, University Club, and Masonic Lodge.

After graduation from Stanford, Dick was employed by the General Petroleum Corporation from 1923 until 1925, after which he became geologist for the California Petroleum Corporation of Los Angeles. In 1928 he entered consulting practice in which activity he continued until the time of his death.

Dick was very successful in consulting work and was well liked and professionally respected. His success was due in part to his keen interest in the industry as a whole, and the people with whom he was in contact. He was an aggressive, clear thinker who thoroughly digested the data available and had the ability and tenacity to carry through with his ideas. He did a great deal of his own leasing and made a point of being well acquainted with his land owners and their problems.

Perhaps Dick's most distinguishing trait was the active interest he maintained in a wide variety of subjects. He was interested not only in his family and friends, but well informed on the activities of his university, as well as local and national government. Unlike most, he would take the time and make the effort to assert his ideas in person, or by letter to the men shaping our legislative policies.

Dick will be missed by his many friends, all of whom join in extending their heartfelt sympathy to his wife and family.

Mr. Crandall is survived by his wife Irella F. Crandall whom he married while still in Stanford, two sons, Richard R., Jr., who is now attending the University of California Agricultural College at Davis, a younger son, Bradford, and a daughter, Ann, attending Stanford University. He also leaves a brother Kenneth Crandall, vice-chairman of the board of directors of the California Company (a Standard Oil Company of California subsidiary), and a sister, Mrs. Gilbert Blackmore.

L. S. CHAMBERS

Los Angeles, California

October 21, 1949

ARTHUR GILBERTSON HUTCHISON

(1902-1949)

His friends throughout the world were shocked to hear of the sudden and tragic death, on August 6, of Arthur Hutchison, senior geologist of the Shell Group of oil companies, as a result of a fall while examining a limestone cliff section during a holiday in Tenby, Pembrokeshire, Wales.

"Hutch" was known wherever he had been located, from Borneo to Venezuela, by his unfailing cheerful personality and capacity for friendship. He did not have one enemy and he had an unequalled talent for making and keeping in touch with his friends; these include head-hunting Dyaks who idolized him in his early days in the Malayan jungle and many of his old negro Trinidad pit-diggers who still beg for news of him.

Arthur Gilbertson Hutchison was born in Aberdeen, Scotland, on August 12, 1902, and was educated at Aberdeen Grammar School and at the University of Aberdeen, where he graduated, B.Sc., with first-class honors in geology in 1926. "Hutch" was essentially a naturalist and he had a hard struggle deciding whether biology or geology should take precedence, but geology won, and after graduating he spent two years in research work at Cambridge, taking his Ph.D. degree there in 1929. His thesis was an outstanding dissertation on the metamorphism of the Dalradian limestone of Deeside, Aberdeenshire.

"Hutch" joined the Shell Group on September 16, 1929, and was posted to Malaya where he remained on bush work for three years. He turned out to be a first-class jungle man, but during this time he contracted internal parasite trouble which was to remain with him for the rest of his life. In 1932 he accepted the offer of a demonstratorship in the

Sedgwick Museum, Cambridge, but he decided that his tropical illness incapacitated him from doing full justice to this appointment and he resigned after a few months, returning to the Shell Group when he was posted to Trinidad in 1933. He remained in Trinidad until January, 1941, being appointed chief geologist of United British Oilfields of Trinidad in 1936.

In 1941 he was appointed liaison geologist between the Burmah and Shell oil companies, and spent exactly a year in Yenangyaung, being forced out via Sumatra and Java before the advancing Japs, who had already captured Singapore. He reached Australia in February, 1942, and was lent to the Australian Government to help instruct flying personnel in the interpretation of aerial photographs. Subsequently he worked with Shell Queensland Proprietary Ltd. until April, 1943, when he returned to London to assist the Bataafsche Pet. Mij. who had set up a war-time organization formed of a nucleus of technical personnel from the head office in The Hague who managed to get to London just before or after the invasion of Holland. With the balance of this organization, Dr. Hutchison returned to Holland toward the end of 1945 and remained there until April, 1948, when he made a trip to Venezuela on loan to the Caribbean Petroleum Company in Caracas. He left Venezuela in January, 1949, making the return trip to Holland via Colombia, Ecuador, and the United States.

In July of this year, he was given two months on leave from his important post in The Hague and, after visiting his sister in Wales, went to Tenby on the Pembrokeshire Coast for holiday of two weeks. His summer vacation in Tenby was, as usual with "Hutch," a busman's holiday, his rucksack and geological hammer daily accompanying him on solitary cliff expeditions along the coast. Although an experienced climber, he must have slipped and suffered a fractured skull, which resulted in his death. His body, washed out to sea, was not recovered for ten days.

It is difficult to believe that "Hutch" has gone, but if it had to be, he would have wished for no other end, with the sun overhead, the sea at his feet, his hammer in his hand.

Dr. Hutchison was a member of the American Association of Petroleum Geologists since 1939. He was elected a fellow of the Geological Society of America in 1943. He was unmarried and is survived by his father and sister. His contagious keenness for geology, his good fellowship, his lovable personality will be sincerely missed and mourned by a host of friends in all parts of the world.

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J. E. SMITH

Maracaibo, Venezuela,
September 9, 1949

AT HOME AND ABROAD

NEWS OF THE PROFESSION

An "Illustrated Catalogue of Japanese Tertiary Smaller Foraminifera" is in course of preparation by KIYOSHI ASANO of the department of geology and paleontology, Tohoku University, Sendai, Japan, with the assistance of LEO W. STACH, formerly micropaleontologist with the Australasian Petroleum Company, Port Moresby, Papua, and now head of the Petroleum Branch, Natural Resources Section, Supreme Commander for the Allied Powers, Tokyo, Japan. It is proposed to issue the set of 10 sheets of the family Nonionidae at a price of 50 cents per set. Inquiries may be addressed to Leo W. Stach, Natural Resources Section, GHQ, SCAP, APO 500, c/o PM, San Francisco, California.

STUART ST. CLAIR, consulting geologist and engineer, returned to New York in October after 20,000 miles over Africa by air safari. He was mineral consultant to Sir Alexander Gibb & Partners of London and Overseas Consultants, Incorporated, of New York, engineering firms retained by the British Colonial Office to conduct a reconnaissance survey of a proposed connecting link between the Rhodesian and East Africa Railway Systems. St. Clair assessed the mineral potential along and adjacent to the survey route. All of Tanganyika and much of Kenya, Nyasaland, and Northern and Southern Rhodesia, and a little of Belgian Congo and Portuguese East Africa were covered.

SHERMAN A. WENGERD, member of the geological staff at the University of New Mexico, and petroleum consultant in Albuquerque, lectured on "Geology of Majuro Atoll, Marshall Islands" before the Dallas Geological Society on October 20. He stressed the sedimentational history of reef growth and destruction, which is timely in view of current reef exploration for oil in Texas and Canada. On October 3, Wengerd delivered a paper before the regional meeting on the American Society of Photogrammetry in Denver, entitled "The Geologist and the Aerial Photograph." The latter paper concerned education of the geologist in the utilization of aerial photographs in the search for petroleum.

At the meeting of the Houston Geological Society, October 24, MAX BORNHAUSER, of the Continental Oil Company, spoke on "Control of Petroleum Accumulation by Sedimentary Facies in South Louisiana."

At a recent meeting of the Illinois Geological Society the final draft was presented of the part of the cross section through Illinois made in conjunction with the A.A.P.G. geological names and correlations committee under L. E. WORKMAN. The Society has decided to sell this cross section along with about 10 pages of descriptive material for \$3.00 a copy. Inquiries should be addressed to T. E. WALL, 914 Main Street, Mt. Vernon, Illinois.

New officers of the Illinois Geological Society are: president, JOSEPH NEELY, Magnolia Petroleum Company, Mt. Vernon; vice-president, C. W. DONNELLY, Ohio Oil Company, Marshall; and secretary-treasurer, T. E. WALL, consultant, Mt. Vernon, Illinois.

The Liege International Fair will be held on April 29-May 14, 1950, at Liege, Belgium. Exhibits include those of mining, metallurgy, mechanical engineering, and electricity in industry.

A. B. McCOLLUM is chief geophysicist for the Taylor Refining Company and the Coastal Refineries, Inc., and assistant chief geologist for the Coastal Refineries, Inc., at McAllen, Texas.

ROBERT KLABZUBA is with the Texas Pacific Coal and Oil Company at Fort Worth, Texas.

RALPH D. CHAMBERS, formerly with the Richfield Oil Company, is with Vincent and Welch, Inc., Midland, Texas.

JOHN S. REDFIELD is associated in consulting work with W. M. PLASTER at 624 Ardis Building, Shreveport, Louisiana. Redfield recently resigned from his position as assistant secretary of the Geological Society of America in New York City.

MAX L. KRUEGER, recently resigned as Rocky Mountain division manager, Union Oil Company of California, to accept a position with the Conorada Petroleum Corporation as vice-president in charge of exploration, with headquarters in New York City, has decided to remain in the Rocky Mountain area to enter private geological consulting practice. He will retain offices in the Converse Building, Laramie, Wyoming, and will specialize in oil and gas exploration work in the Rocky Mountains, California, and the Mid-Continent. Krueger's resignation with Union Oil became effective November 15.

The Appalachian Geological Society, Charleston, West Virginia, announces publication of a 550-page, cloth-bound book (its *Bulletin*, Vol. 1, 1949), containing 47 technical papers, including articles on geological problems, geophysics, acidizing, electric well surveying, gas storage, brine, oil and gas analysis, secondary recovery, tempering and dressing cable-tool bits, corrosion, plastics, and many other subjects. The book is available at \$6.75 per copy, postpaid, by writing the Appalachian Geological Society, Box 2605, Charleston 29, West Virginia.

IRA H. CRAM, vice-president in charge of exploration for the Continental Oil Company, Ponca City, Oklahoma, with a staff of geologists, is being transferred to Houston, Texas,

The A.A.P.G. research project No. 11 on "Experimental Tectonics" is being carried on by the department of geology of the Texas A. & M. College and the Texas Engineering Experiment Station. This project experiment is known as "The Study of the Tectonics of Salt Domes by the Use of Scale Models." Professor S. A. LYNCH, head of the department of geology, reports that the work is being done by A. N. McDOWELL, assistant professor of geology, and T. J. PARKER, associate professor of geology.

C. E. BREHM, independent oil producer of Mt. Vernon, Illinois, has opened a geological office at Evansville, Indiana, where A. B. CARLISLE is in charge. Carlisle was formerly with the Sohio Petroleum Company as eastern division geologist.

A.A.P.G. president C. W. TOMLINSON, of Ardmore, Oklahoma, gave a talk on "Odd Geologic Structures of Southern Oklahoma" before the Shawnee Geological Society, Shawnee, Oklahoma, at the September meeting.

New officers of the New Orleans Geological Society are: president, LESLIE BOWLING, consultant; vice-president, A. P. CLAUDET, Schlumberger Well Surveying Corporation; secretary, E. A. GIBSON, Humble Oil and Refining Company; treasurer, CHARLES DE BLIEUX, consultant.

F. C. SEALEY was recently elected vice-president of the Bahreim Petroleum Company, Ltd., in charge of exploration and production.

F. D. DAMON is geologist for the Big Chief Drilling Company at Oklahoma City.

A.A.P.G. PACIFIC SECTION MEETING, LOS ANGELES,
NOVEMBER 17-18, 1949E. HAROLD RADER¹

Los Angeles, California

The 26th annual meeting of the Pacific Section was held, November 17 and 18, 1949, at the Ambassador Hotel in Los Angeles. Concurrent meetings were held by sections of the Society of Economic Paleontologists and the Society of Exploration Geophysicists.

The annual luncheon was held in the Embassy Room at the Ambassador, on Thursday, at noon, at which time C. W. TOMLINSON, national president, talked to the members regarding the activities of the Association.

At the annual business meeting, held on Friday, November 18, the following officers were elected to serve the Pacific Section for the year 1949-1950: president, J. R. PEMBERTON, 903 Petroleum Building, 714 West Olympic Boulevard, Los Angeles; vice-president, ARTHUR S. HUEY, Hancock Oil Company of California, 2828 Junipero Avenue, Long Beach; secretary-treasurer, MILTON W. LEWIS, 904 Petroleum Building, 714 Olympic Boulevard, Los Angeles.

The total registration was 625, including 16 A.A.P.G. members outside of the Pacific Section and 4 A.A.P.G. members from foreign countries. The Pacific Section was pleased to have in attendance more than 150 students from geological schools in the Los Angeles area. The meeting closed with the semi-formal dinner-dance, which was attended by approximately 475 people, in the Embassy Room of the Ambassador Hotel.

The San Joaquin Geological Society, Bakersfield, California, elected the following officers for the ensuing year: chairman, J. J. BRYAN, Union Oil Company of California; vice-chairman, KENNETH F. KRAMMES, The Texas Company; secretary-treasurer, RALPH E. BRODEK, Western Gulf Oil Company, Box 1392, Bakersfield, California.

The Northern California Geological Society, San Francisco, elected the following officers for the ensuing year: chairman, W. E. DILLON, Tide Water Associated Oil Company; vice-chairman, CHARLES M. CROSS, Honolulu Oil Corporation; secretary-treasurer, DANIEL J. PICKRELL, Golden Gate Petroleum Company, 465 California Street, San Francisco, California.

The Coast Geological Society elected the following officers for the ensuing year: chairman, LOWELL E. REDWINE, Honolulu Oil Corporation, Santa Barbara; vice-chairman, IRVING T. SCHWADE, Richfield Oil Corporation, Ventura; secretary, RICHARD B. HAINES, Continental Oil Company, Box 450, Ventura; treasurer, WILLIAM H. THOMAS, Shell Oil Company, Inc., Box 691, Ventura, California.

¹ Secretary-treasurer, Pacific Section.

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ERRATA

- P. 1447, Art. III, Sec. 1, 1st paragraph, 3d line from end should read: "construed to exclude teachers and research workers in geology in recognized institutions," etc.
- P. 1456, Sec. 12, 2d line, delete "the methods used to locate."
- P. 1456, Sec. 12, 5th line, "twenty-four" should read thirty-five.
- P. 1637, 1st paragraph, 1st line, Alfred Seen should be Alfred Senn.

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1348 Esperson Bldg., Houston, Tex.
Business Manager - - - - - Colin C. Campbell
Room 210, 817 South Boulder, Tulsa, Oklahoma
P.O. Box 1614

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President - - - - - Clifton W. Johnson
Richfield Oil Corporation
Room 430, Richfield Bldg.
Los Angeles 13, California
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Chanslor-Canfield Midway Oil Company
4549 Produce Plaza West, Los Angeles 11
Secretary-Treasurer - - - - - Harold E. Rader
Standard Oil Company, Box 2437, Terminal Annex
Los Angeles 34
Monthly meetings. Visiting geologists are welcome.

CALIFORNIA

SAN JOAQUIN GEOLOGICAL SOCIETY BAKERSFIELD, CALIFORNIA

President - - - - - Robert B. Hutcheson
The Superior Oil Company, Box 1031
Vice-President - - - - - Floyd L. Johnson
Honolulu Oil Corporation
Secretary-Treasurer - - - - - Maxwell G. Caben
Seaboard Oil Company of Delaware, Box 7

Dinner meetings on 2d Tuesday of each month or
as announced, El Tejon Hotel, Bakersfield.

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF GEOLOGISTS DENVER, COLORADO

President - - - - - Dart Wantland
U. S. Reclamation Service
1st Vice-President - - - - - S. W. Lohman
U. S. Geological Survey
136 New Customhouse
2d Vice-President - - - - - E. W. Scudder
J. M. Huber Corporation
Box 2098
Secretary-Treasurer - - - - - Kenneth L. Gow
Superior Oil Company of California
506 First National Bank Building
Evening dinner (6:30) and technical program
(8:00) first Tuesday each month or by announce-
ment.

FLORIDA

SOUTHEASTERN GEOLOGICAL SOCIETY Box 841 TALLAHASSEE, FLORIDA

President - - - - - W. C. Blackburn
Humble Oil and Refining Company, Box 506
Secretary-Treasurer - - - - - Albert A. Raasch
Humble Oil and Refining Company,
Box 506

Meetings will be announced. Visiting geologists
and friends are welcome.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - Joseph Neely
Magnolia Petroleum Company
Box 535, Mt. Vernon
Vice-President - - - - - C. W. Donnelly
Ohio Oil Company
Marshall
Secretary-Treasurer - - - - - T. E. Wall
Consultant, Box 206, Mt. Vernon
Meetings will be announced.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY EVANSVILLE, INDIANA

President - - - - - H. W. Bodkin
Superior Oil Company
Vice-President - - - - - D. G. Sutton
Sun Oil Company, Box 717
Secretary-Treasurer - - - - - J. B. Vaughan
Ashland Oil and Refining Company
Henderson, Kentucky

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY WICHITA, KANSAS

President - - - - - Don W. Payne
Sinclair Prairie Oil Company
Vice-President - - - - - T. G. Wright
Stanolind Oil and Gas Company
Secretary-Treasurer - - - - - Victor F. Reiserer
Superior Oil Company, 510 K.F.H. Bldg.

Regular Meetings: 7:30 P.M., Geological Room,
University of Wichita, first Tuesday of each month.
Noon luncheons, first and third Monday of each
month at Wolf's Cafeteria. The Society sponsors
the Kansas Well Log Bureau, and the Kansas Well
Sample Bureau, 508 East Murdock. Visiting geolo-
gists and friends welcome.

LOUISIANA

NEW ORLEANS
GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - Leslie Bowling
Consultant, 529 Whitney Building
Vice-President and Program Chairman - - - - - A. P. Claudet
Schlumberger Well Surveying Corporation
451 Canal Building
Secretary - - - - - E. A. Gibson
Humble Oil and Refining Company
1405 Canal Building
Treasurer - - - - - Charles DeBlieux
Consultant, 902 Baronne Building
Meets the first Monday of every month, October-
May, inclusive, 12 noon, St. Charles Hotel.
Special meetings by announcement. Visiting geol-
ogists cordially invited.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL
SOCIETY

LAKE CHARLES, LOUISIANA

President - - - - - W. B. Neill
Stanolind Oil and Gas Company
Vice-President - - - - - Pete Haberstick
Atlantic Refining Company
Secretary - - - - - James M. Whatley
Union Sulphur Company
Treasurer - - - - - Bert C. Timm
Magnolia Petroleum Company

Meetings: Dinner and business meetings third
Tuesday of each month at 7:00 P.M. at the Ma-
jestic Hotel. Special meetings by announcement.
Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI
GEOLOGICAL SOCIETY

BOX 2253, WEST JACKSON, MISSISSIPPI

President - - - - - E. T. Monsour
Consultant, Box 2571, West Jackson
Vice-President - - - - - Charles E. Buck
Skelly Oil Company, 100 East Pearl Building
Treasurer - - - - - W. H. Knight
Union Producing Company
Secretary - - - - - F. T. Holden
Carter Oil Company, Box 1490

Meetings: First and third Thursdays of each
month, from October to May, inclusive, at 7:30
P.M., the Edwards Hotel, Jackson, Mississippi.
Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE
GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - I. Curtis Hicks
Phillips Petroleum Company
Vice-President - - - - - Earl Westmoreland
Seaboard Oil Company
Secretary-Treasurer - - - - - Frank Millard
Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 6:30 P.M. on the
first and third Thursday of every month from Sep-
tember to May, inclusive, at the Ardmore Hotel.

THE SHREVEPORT
GEOLOGICAL SOCIETY

SHREVEPORT, LOUISIANA

President - - - - - Victor P. Grage
Consultant, 415 Ardis Building
Vice-President - - - - - R. T. Wade
Schlumberger Well Surveying Corporation
Box 92
Secretary-Treasurer - - - - - Charles A. Hickcox
Centenary College, Box 750

Meets monthly, September to May, inclusive, in
the State Exhibit Building, Fair Grounds. All
meetings by announcement.

MICHIGAN

MICHIGAN

GEOLOGICAL SOCIETY
MOUNT PLEASANT, MICHIGAN

President - - - - - Glenn C. Sleight
Sun Oil Company, Taylor Building
Vice-President - - - - - Manley Osgood, Jr.
Consultant, 302 S. Arnold St.
Secretary-Treasurer - - - - - Jack Mortensen
Sohio Oil Company, 601 S. Main St.
Business Manager - - - - - Kenneth G. Walsworth
Dept. Conservation, Box 176

Meetings: Monthly, November through May, at
Michigan State College, East Lansing, Michigan.
Informal dinners at 6:30 P.M. Papers follow
dinner. Visitors welcome.

NEW YORK

EASTERN SECTION
AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS
NEW YORK, NEW YORK

President - - - - - Hollis D. Hedberg
Gulf Oil Corp., 17 Battery Place
Vice-President - - - - - Douglas A. Greig
Standard Oil Co., (N.J.), 30 Rockefeller Plaza
Treasurer - - - - - Marshall Kay
Department of Geology, Columbia University
Secretary - - - - - Godfrey F. Kaufmann
Standard-Vacuum Oil Co., 26 Broadway,
Room 1556

Meetings by announcement to members. Visiting
geologists and friends cordially invited.

OKLAHOMA CITY
GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - Rizer Everett
Carter Oil Company
Vice-President - - - - - Richard L. Roberts
Vickers Petroleum Company
Secretary - - - - - L. W. Curtis
Sohio Petroleum Company
Treasurer - - - - - Joseph M. Sears
Independent

Meetings: Technical program each month, subject
to call by Program Committee, Oklahoma City
University, 24th Street and Blackwelder. Lunch-
cons: Every second and fourth Thursday of each
month, at 12:00 noon, Y.W.C.A.

OKLAHOMA

SHAWNEE
GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - Doyle M. Burke
The Texas Company, Box 1007

Vice-President - - - - - Jack W. Davies
Halliburton Oil Well Cementing Company

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169

Meets the third Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

PENNSYLVANIA

PITTSBURGH GEOLOGICAL
SOCIETY
PITTSBURGH, PENNSYLVANIA

President - - - - - Charles F. Bassett
Gulf Oil Corporation, Box 1166

Vice-President - - - - - R. E. Sherrill
University of Pittsburgh

Secretary - - - - - C. E. Prouty
University of Pittsburgh

Treasurer - - - - - Sidney S. Galpin
Peoples Natural Gas Company
345 William Penn Place

Meetings held each month, except during the summer. All meetings and other activities by special announcement.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - L. H. Lukert
The Texas Company, Box 2420

1st Vice-President - - - - Daniel A. Busch
Carter Oil Company, Box 801

2d Vice-President - - - - John M. Nash
Shell Oil Company, Box 1191

Secretary-Treasurer - - - - Mary Whitehead
Stanolind Oil and Gas Company, Box 591

Editor - - - - - Oscar E. Wagner, Jr.
Mid-Continent Petroleum Corporation, Box 381

Business Manager, Digest - - - - V. L. Frost
Ohio Oil Company, Thompson Building

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Lorton Hall. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

TEXAS

ABILENE GEOLOGICAL SOCIETY
ABILENE, TEXAS

President - - - - - J. R. Day
Pan American Production Company

Vice-President - - - - - David M. Grubbs
Drilling and Exploration Company

Secretary-Treasurer - - - - C. S. Noland
Skelly Oil Company

Meetings: 2d Thursday of each month, 7:30 P.M., Wooten Hotel.

TEXAS

CORPUS CHRISTI GEOLOGICAL
SOCIETY

CORPUS CHRISTI, TEXAS

President - - - - - James D. Burke
Seaboard Oil Company of Delaware, Box 601

Vice-President - - - - - W. H. Wallace, Jr.
La Gloria Corporation, Driscoll Building

Secretary-Treasurer - - - - H. W. Volk, Jr.
Tide Water Associated Oil Company
Driscoll Building

Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

DALLAS GEOLOGICAL SOCIETY
DALLAS, TEXAS

President - - - - - John T. Rouse
Magnolia Petroleum Company
P.O. Box 900

Vice-President - - - - - H. V. Tygrett
The Atlantic Refining Company
P.O. Box 2819

Secretary-Treasurer - - - - Gilbert P. Moore
Consulting, 301 Continental Building

Executive Committee - - - - Edgar Kraus
Atlantic Refining Company
Box 2819

Meetings: Monthly luncheons and night meetings by announcement.

EAST TEXAS GEOLOGICAL
SOCIETY

TYLER, TEXAS

President - - - - - G. C. Clark
Stanolind Oil and Gas Company
Box 660

Vice-President - - - - - R. M. Trowbridge
Consultant, 225 Owen Building

Secretary-Treasurer - - - - Rosella L. Bunch
Shell Oil Company, Inc., Box 2037

Luncheons: Each week, Monday noon, Blackstone Hotel.
Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

FORT WORTH
GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - H. C. Vanderpool
Texas Pacific Coal and Oil Company
Box 2110

Vice-President - - - - - W. Baxter Boyd
Continental Oil Company
1710 Fair Building

Secretary-Treasurer - - - - Thomas Nichols
Rowan Oil Company
Commercial Standard Building

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

TEXAS

HOUSTON
GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President Hershah C. Ferguson
Consultant, 935 Mellie Esperson Building
Vice-President R. R. Rieke
Schlumberger Well Surveying Corporation
Secretary James H. McGuirt
Tide Water Associated Oil Company
Treasurer Marjorie Fuqua
Humble Oil and Refining Company

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

PANHANDLE
GEOLOGICAL SOCIETY
AMARILLO, TEXAS

President G. E. Hatton
Phillips Petroleum Company, Box 1761
Vice-President Robert F. Herron
Oil Development Company, 900 Polk St.
Secretary-Treasurer Robert B. Totten
Sun Oil Company, Box 46

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

TEXAS

WEST TEXAS GEOLOGICAL
SOCIETY
MIDLAND, TEXAS
Box 1595

President W. T. Schneider
Honolulu Oil Corporation, Box 1391
Vice-President Ralph D. Chambers
Continental Oil Company, Box 431
Secretary Jesse A. Rogers
The Texas Company, Box 1270
Treasurer John V. Norman, Jr.
Forest Oil Corporation, Box 1821

Meetings will be announced.

WEST VIRGINIA

APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P.O. Box 2603

President W. B. Maxwell
United Fuel Gas Company, Box 1273
Vice-President John Galpin
1901 Kanawha Valley Building
Associate Vice-President H. P. McJunkin
McJunkin Supply Company
Secretary-Treasurer W. T. Ziebold
Spartan Gas Company, Box 766
Editor F. Seigal Workman, Jr.
Acme Engineering Services, Box 923

Meetings: Second Monday, each month, except June, July and August, at 6:30 P.M., Daniel Boone Hotel.

NORTH TEXAS
GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President Joseph W. McDonald
Shell Oil Company, Inc., Box 2010
Vice-President Ralph H. McKinlay
Panhandle Producing and Refining Company
Box 1191
Secretary-Treasurer Walter L. Ammon
Stanolind Oil and Gas Company
Box 1680

Meetings: Luncheon 1st and 3d Thursdays of each month, 12:00 noon, Texas Room, Holt Hotel. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

SOUTH TEXAS GEOLOGICAL
SOCIETY
SAN ANTONIO, TEXAS

President Paul B. Hinyard
Shell Oil Company
2000 Alamo National Building
Vice-President J. Boyd Best
Ohio Oil Company
Secretary-Treasurer Louis H. Haring, Jr.
Stanolind Oil and Gas Company

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

UTAH

UTAH GEOLOGICAL SOCIETY
SALT LAKE CITY, UTAH
P.O. Box 1015

President J. Stewart Williams
Utah State Agricultural College, Logan
Vice-President A. Lee Christensen
Utah Construction Company, Salt Lake City
Corresponding Secretary Reed F. Welch
American Smelting and Refining Co., Salt Lake City
Recording Secretary Max Erickson
University of Utah, Salt Lake City
Treasurer F. W. Christiansen
University of Utah, Salt Lake City

Sponsors an annual field trip for which a guidebook is published.

Meetings by announcement.

WYOMING

WYOMING GEOLOGICAL
ASSOCIATION
CASPER, WYOMING
P.O. Box 545

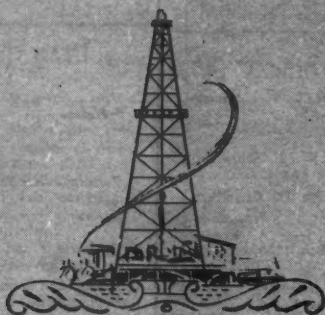
President George W. Berry
Sun Oil Company, Box 1166
1st Vice-President J. H. McCoy
Sinclair Oil and Gas Company, Box 1809
2d Vice-President (Programs) Klaas van der Weg
General Petroleum Corporation, Box 1652
Secretary R. W. Mallory
Stanolind Oil and Gas Company, Box 40
Treasurer Allan Cree
Cities Service Oil Company, Box 792

Informal luncheon meetings every Friday, 12 noon, Townsend Hotel. Visiting geologists welcome. Special meetings by announcement.

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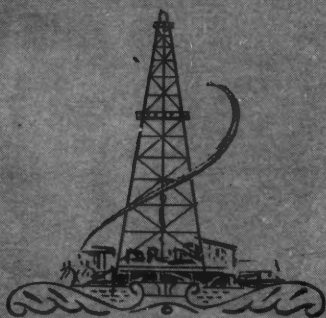
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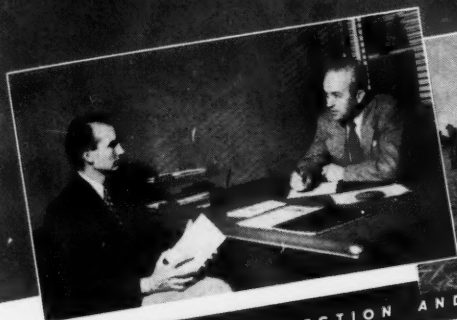


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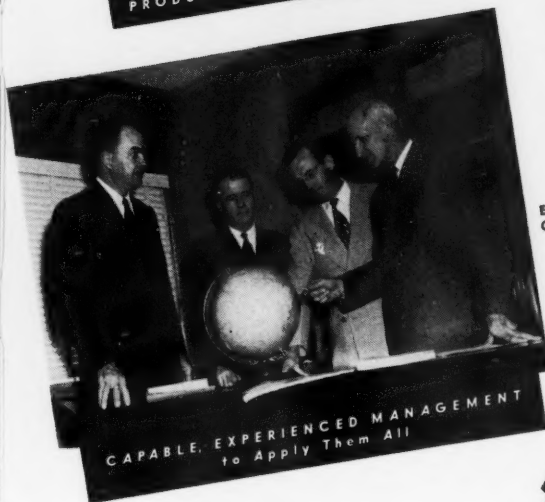
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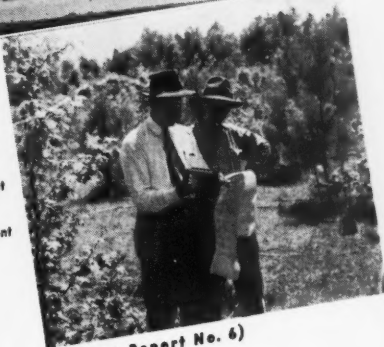


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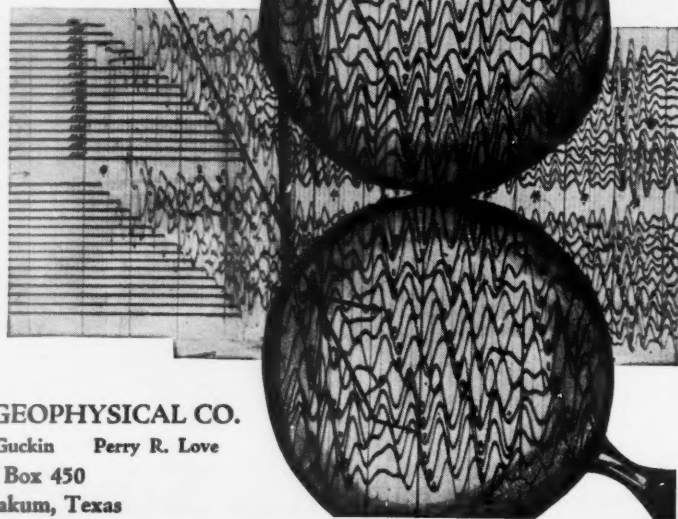
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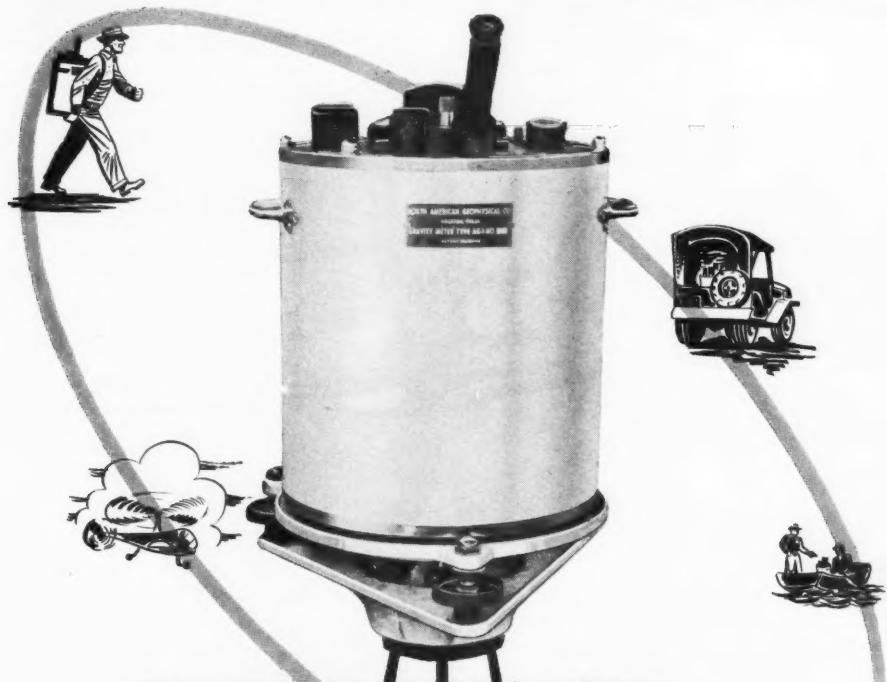


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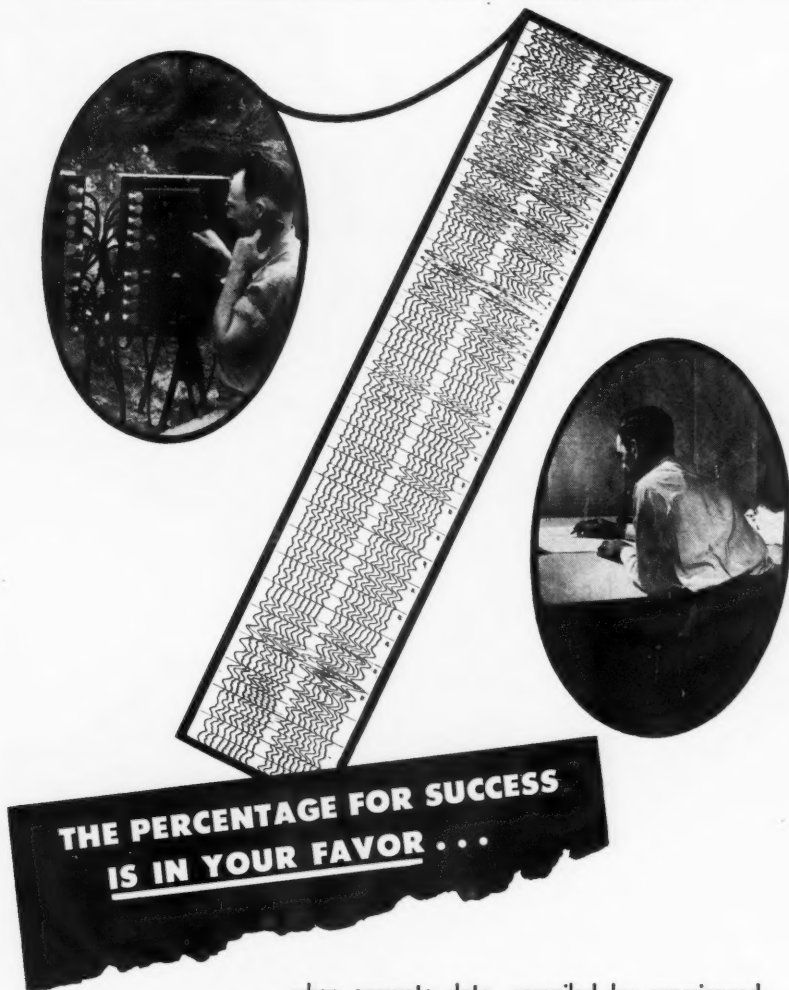


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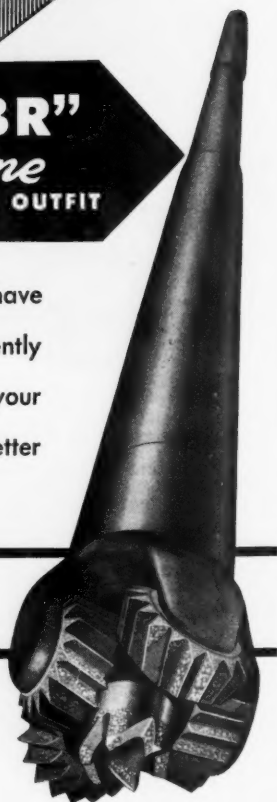
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TECTONIC MAP

Of The

UNITED STATES

Prepared under the Direction of the Committee on Tectonics
Division of Geology and Geography, National Research Council

CHESTER R. LONGWELL, Chairman, PHILIP B. KING, Vice-Chairman
CHARLES H. BEHRE, WALTER H. BUCHER, EUGENE CALLAGHAN, D. F.
HEWETT, G. MARSHALL KAY, ELEANORA B. KNOPE, A. I. LEVORSEN,
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WATERS, ELDRED D. WILSON, A. O. WOODFORD

A Geologic Map of the United States and Adjacent Parts of Canada and Mexico

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The base map shows state boundaries, rivers, a pattern of cities, and 1 degree lines of latitude and longitude.

The scale is 1:2,500,000, or 1 inch = 40 miles. Printed in 7 colors, on 2 sheets, each about 40 x 50 inches. Full map size is about 80 x 50 inches.

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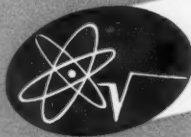
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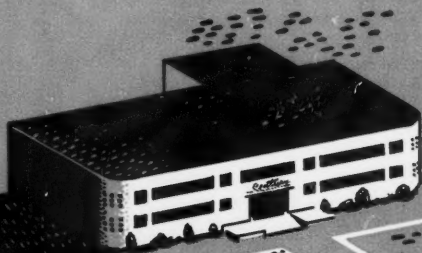
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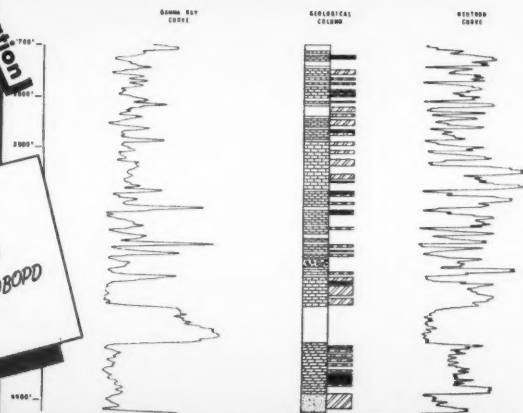
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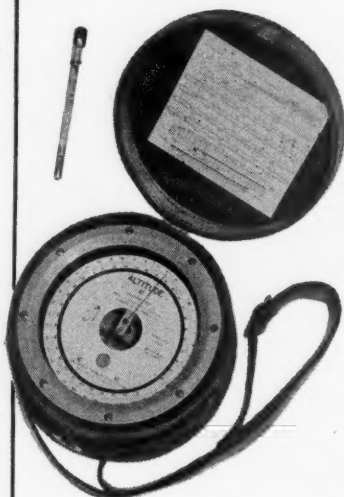
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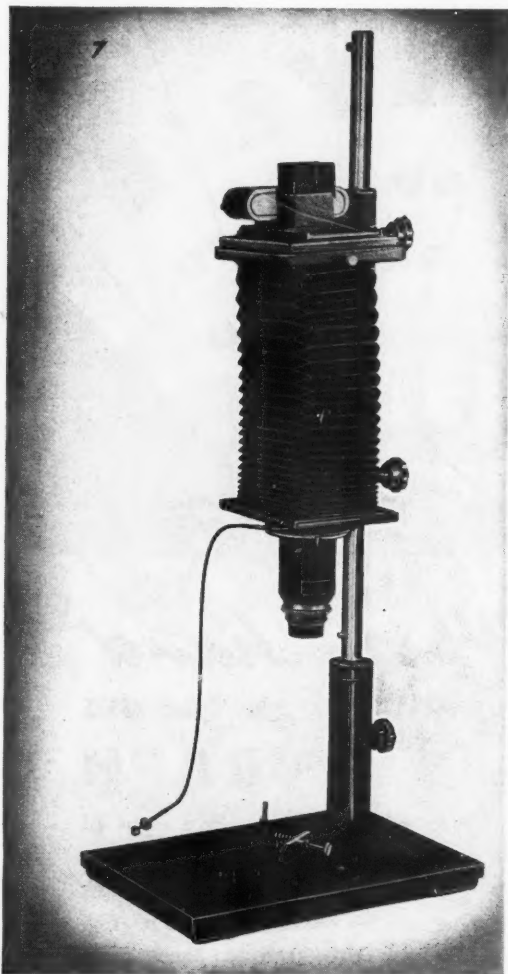
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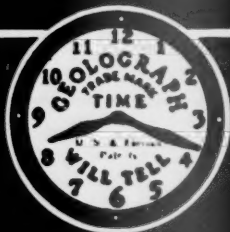
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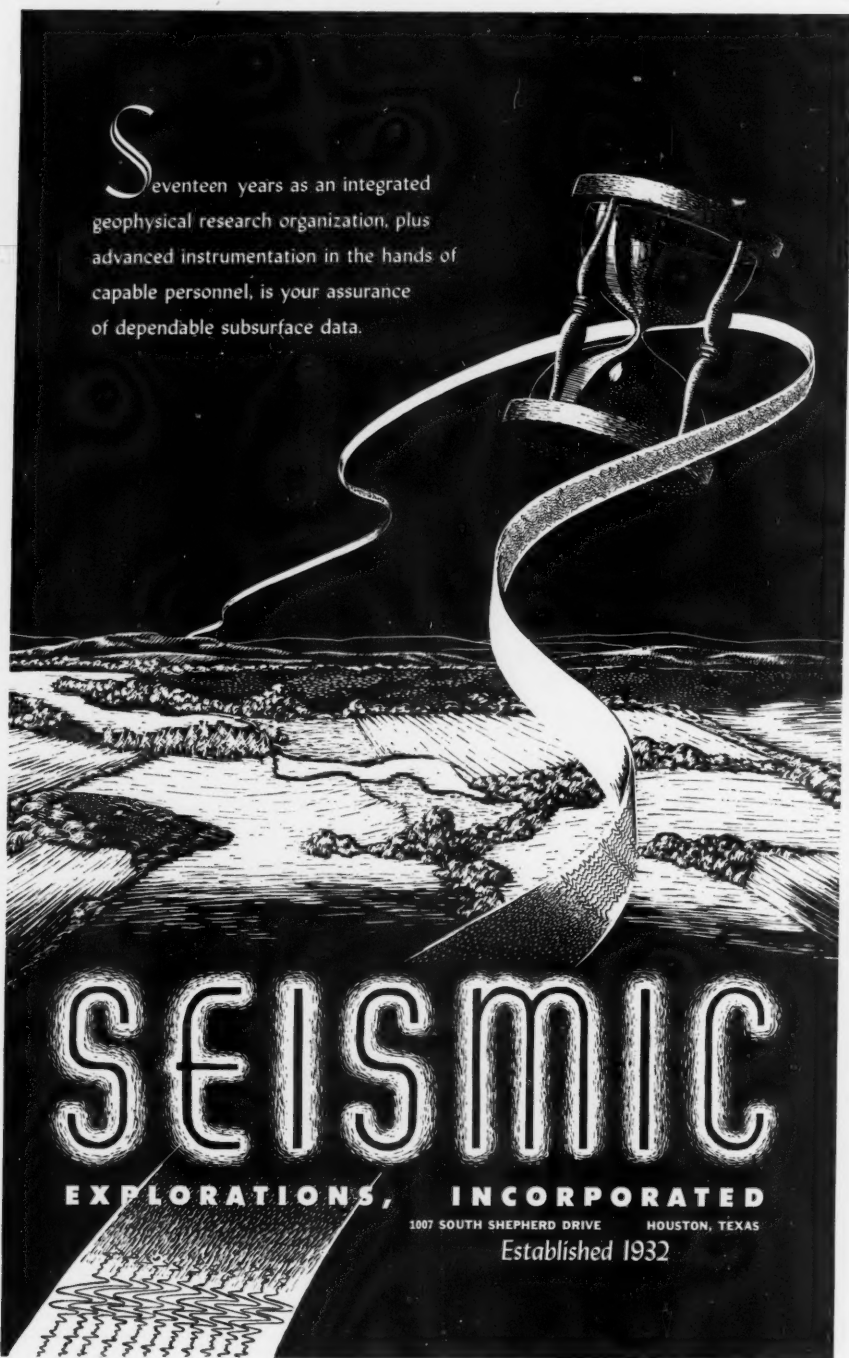
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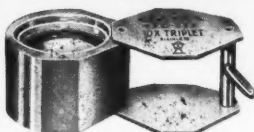
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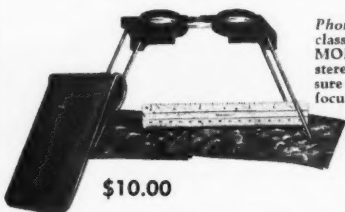


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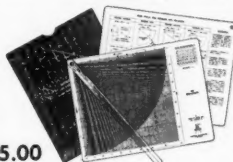
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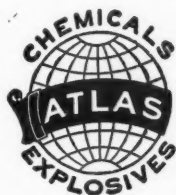
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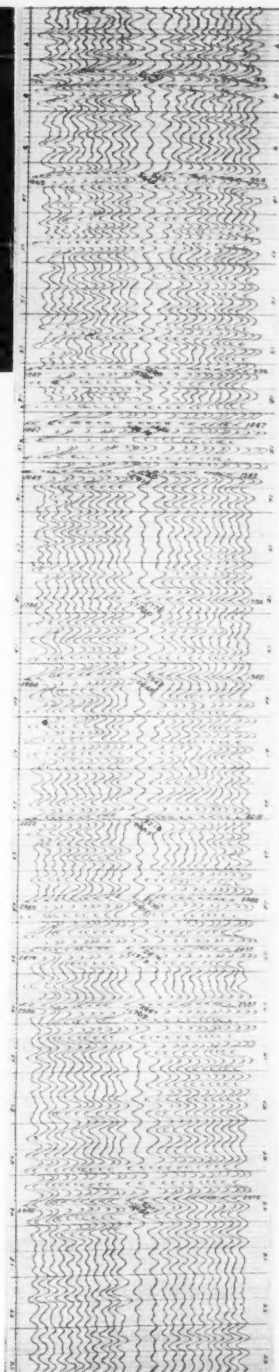
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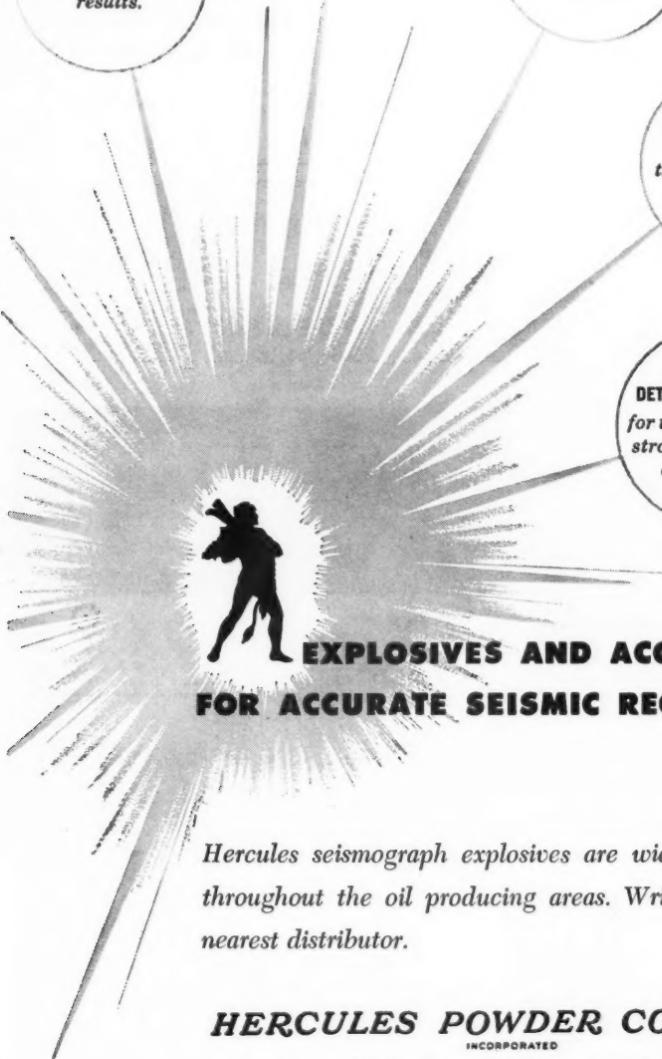
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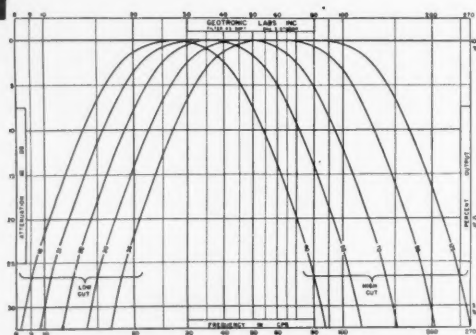
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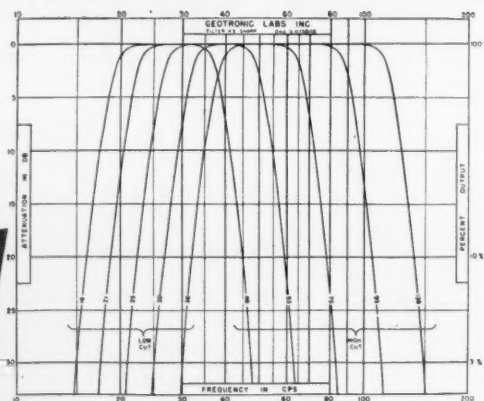
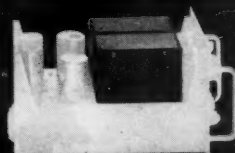
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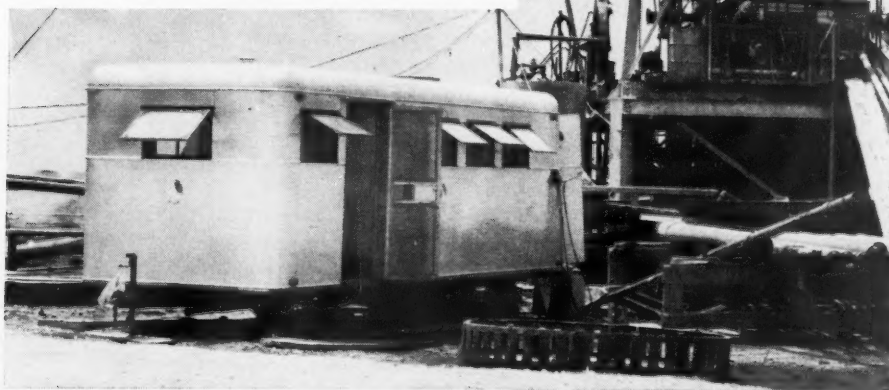
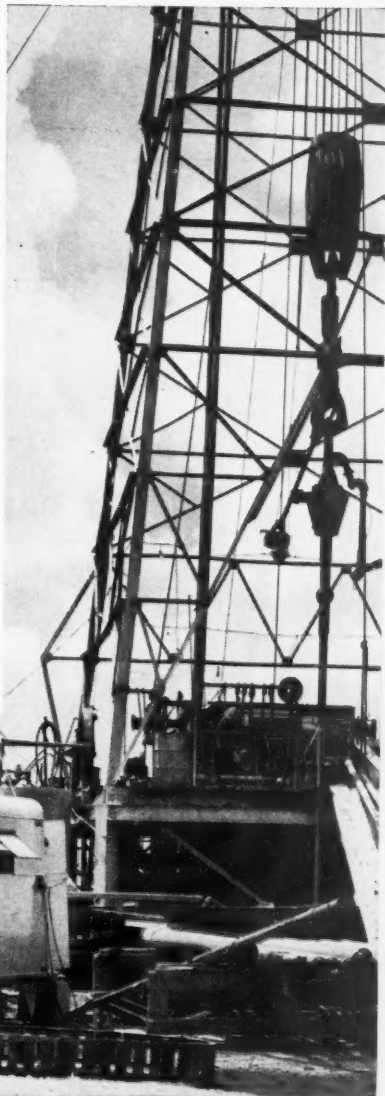
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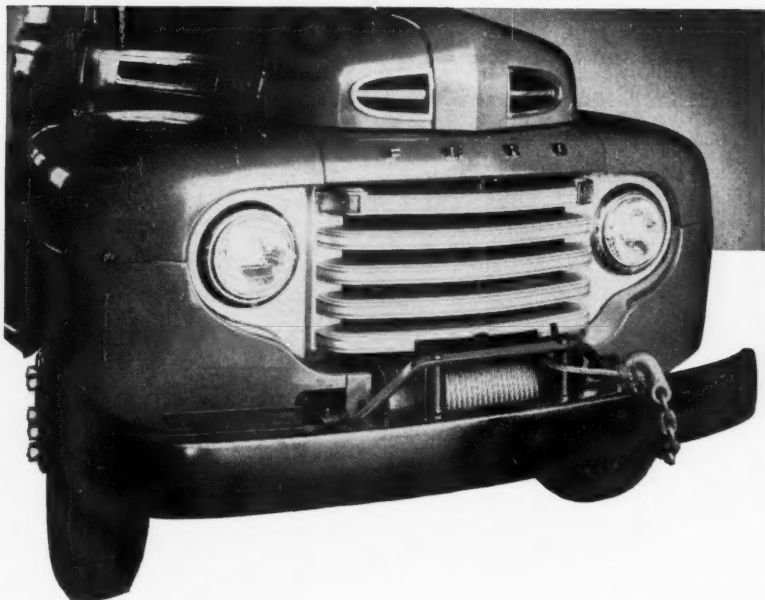
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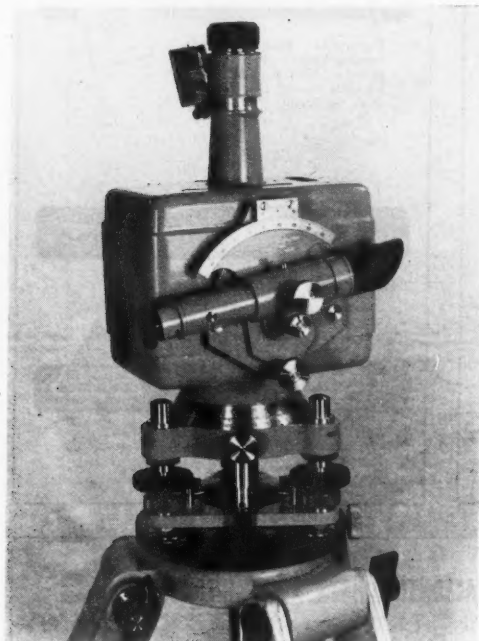
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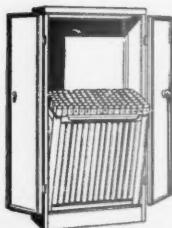
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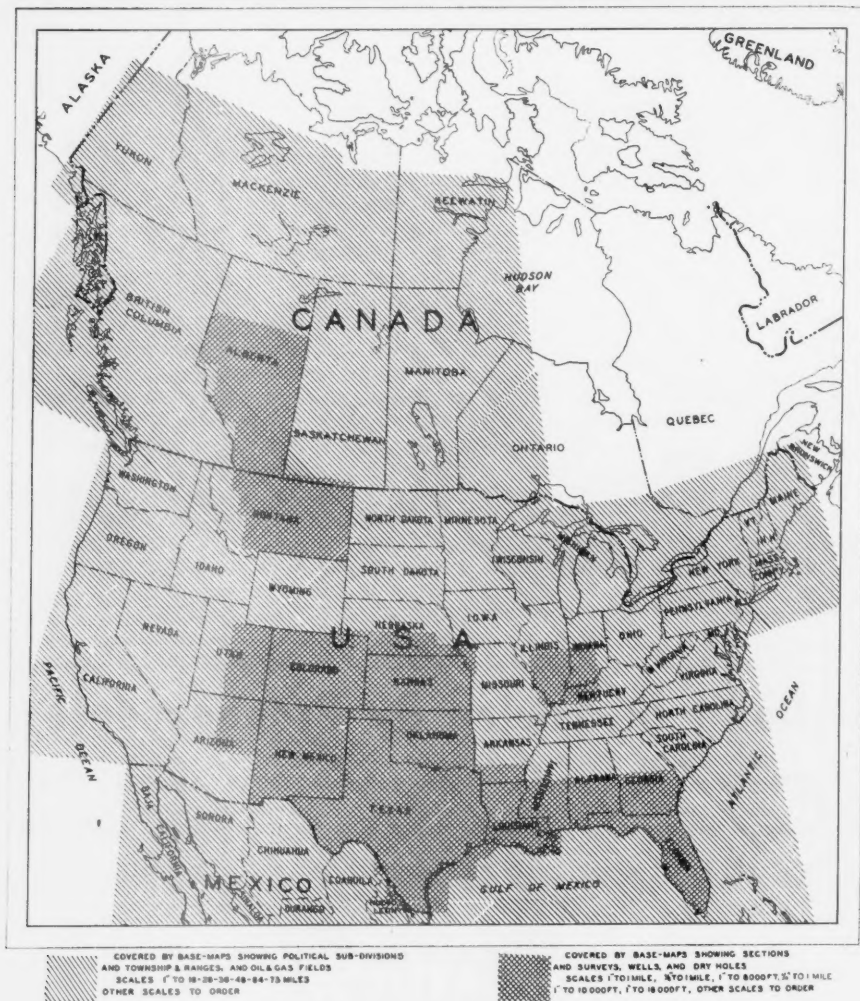
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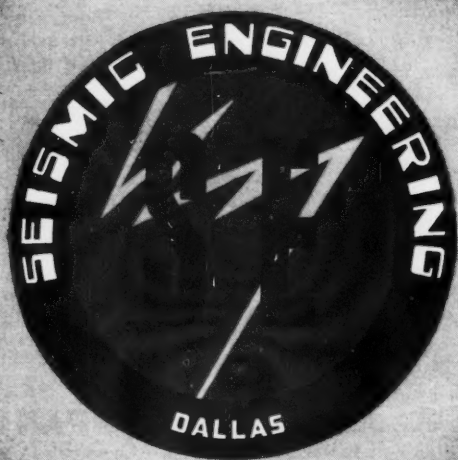
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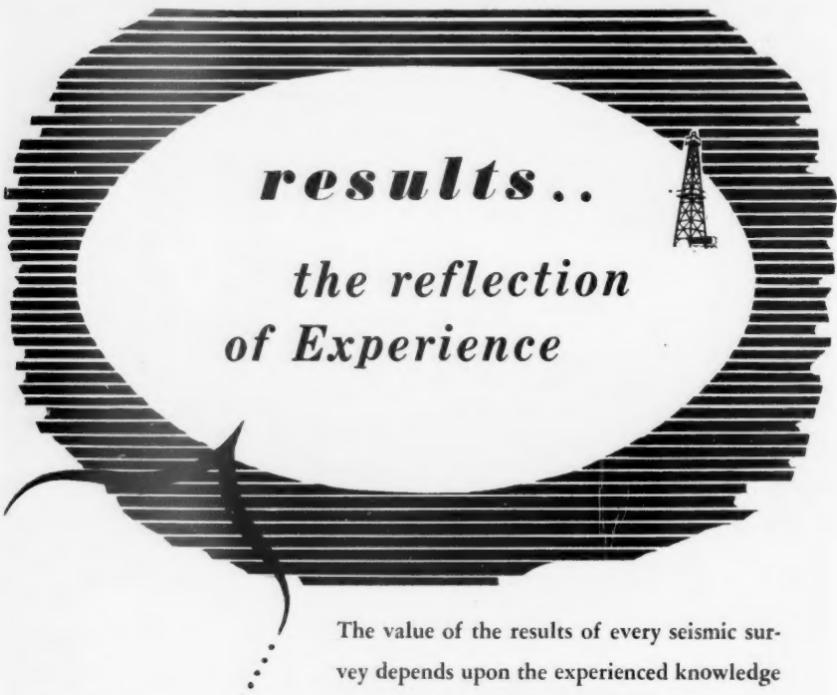
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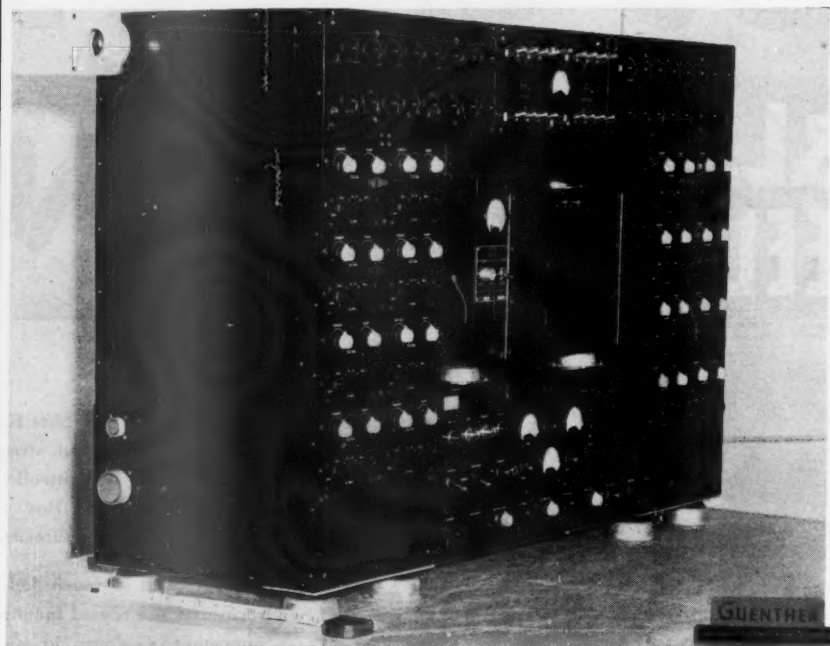
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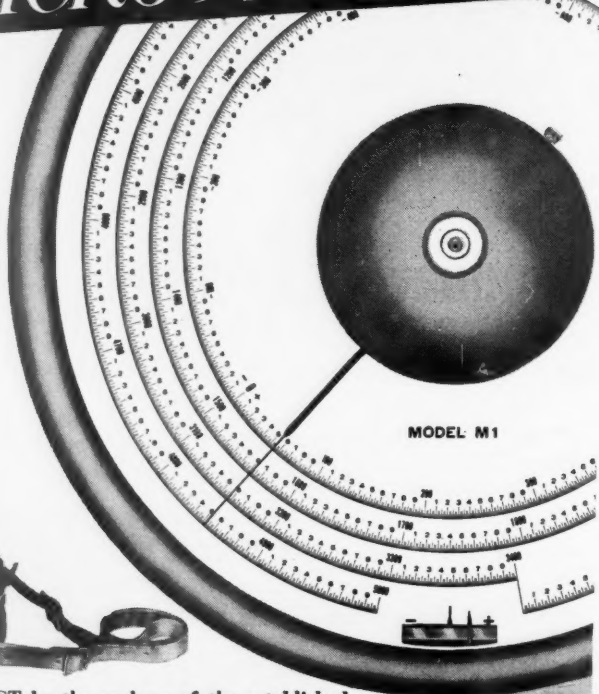
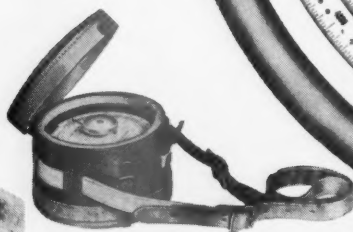
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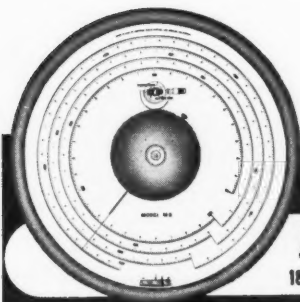
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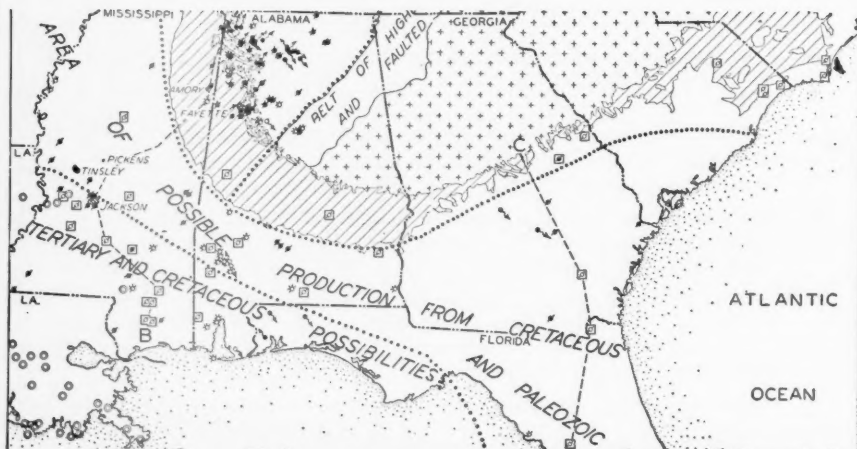
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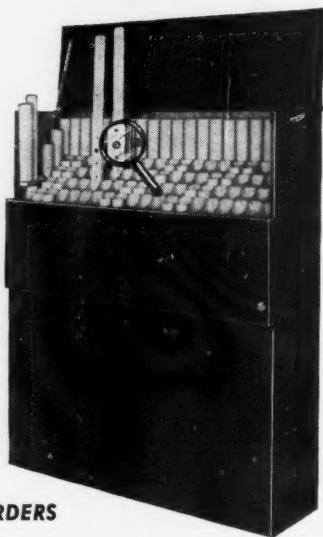
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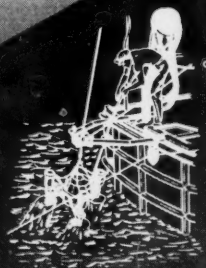
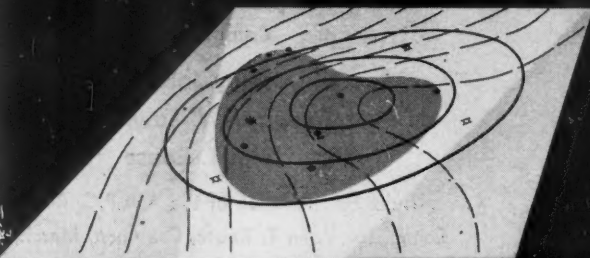
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